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THE RISE OF COPPER WIRE, ITS MANUFACTURE AND USE TO

1900 - A CASE OF INDUSTRIAL CIRCUMSPECTION

A Dissertation in the History of Technology

Barrie Charles Blake-Coleman

This thesis was prepared as requirement for the degree of Master of Philosophy in the Open University and was submitted in April, 1980. The author is 33 years of age and a graduate of the Open University (1971-1974), and also holds a Post Graduate Certificate in Education from Southampton University (1978-1979).

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DEDICATION

To my wife, Clare, without whose help and understanding this work would have been impossible.

My gratitude also, to all those who had faith in me.

ACKNOWLEDGMENTS

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I am particularly indebted to my supervisor, Dr. D. C. Goodman, for guidance which was firm but never restrictive.

ABSTRACT

COPPER WIRE, ITS MANUFACTURE AND USE TO 1900 - A CASE OF INDUSTRIAL CIRCUMSPECTION.

B. C. Blake-Coleman B.A., Cert. Ed.

This work critically examines the principal events and circumstances which influenced the course and rise of a crucial component in modern electrical technology - copper wire.

This material, through successive eras, has played a variety of roles and enjoyed a range of distinct applications. In charting the development, manufacture and use of copper wire, the thesis describes how in its earlier history a traditionally made product, applied to traditional purposes (in arts and trades themselves subject to change) evolved into something which, in property and quality, was entirely different - electrical conductors. By 1850, copper wire can be said to have long begun its exchange of a traditional role for a modern one, having by this time found application as a telegraph conductor, with varying degrees of success. In this respect, early trials in overland and submarine telegraphy, as well as experiments on metallic conductors, are shown to have been major influences in the development of copper wire as an electrical conductor. Hence the transition of copper wire from its traditional qualities and roles to those where it was fit for specialist electrical applications, is fully considered. Careful consideration also is given to the work surrounding the establishment of electrical standards which came out of the need for improved copper conductors.

Apart from the emphasis placed on reviewing those factors important in changing the quality and characteristics of traditional copper wire, an equal level of discussion is given over to considering the condition, growth and changing fortunes of the wire mills and the wire industry during its greatest period of change and expansion - 1750-1900. The pressures felt by the manufacturers during this time (technological, economic and, to some degree, social) are examined as too the state of the attitudes and policies, moulded by changing market demands and levels of prosperity.

The overall object of the study is to give meaning and significance to, and a reasonable interpretation of, the historically important events which shaped the manufacture and application of copper wire. As such, the study critically assesses not only the reasons for the changing fortunes of copper wire, but the failure of the manufacturing effort behind it to emerge, at least by 1900, as a separate and distinct industry.

INTRODUCTION

This study concerns itself with a much neglected subject - the forces and circumstances that moulded the methods of production, organisation and policies of what, by the end of the 19th century, constituted a huge manufacturing effort - copper wire.

In setting out to identify and examine those factors which influenced the ascent of copper wire as a staple commodity, and its manufacture, it would be useful to mention something of the progressive rise in its value, importance and consumption up to the end of the 19th century and to ask why copper wire came to enjoy a position as an indispensable commodity. Moreover, we must go further and enquire as to what we may learn from asking many of the questions posed by the ascent of such an industrial effort. Certainly, there is no disputing the value of copper wire to our modern electrical technology, nor to that of the 19th century. Some indication of the magnitude of the enterprise involved in copper wire making at that time may be gained by considering the statistics relating to the proportion of copper ore processed as "high conductivity copper" and intended for the electrical industry. In the United Kingdom, during the year 1899, some 470,000 tons of copper underwent processing, of which 300,000 tons was estimated to have been used by the electrical industry.¹ A major proportion of this 300,000 tons was produced by the "new" electrolytic process which was becoming a major contributor to copper production² for the electrical industry following the demand for a high purity metal. Of the 300,000 tons of copper routed to the electrical industry, the greater proportion was processed into enormous lengths of various gauges, types and patterns of copper wire.

The statistics stated above - taken as evidence of a distinctive manufacturing effort - are for the most part justification for concluding this study at the close of the 19th century. To terminate at this point is no disservice to the history of the "industry" during the last 79 years; save for some technical advances in draw-plate technology (e.g. the introduction of chrome steel and tungsten carbide dies),³ and some refinements in machinery, little difference would be discernible between a wire-drawing plant of today, and that to be found in a modern wire-mill of the 1900s. The essential technology, therefore, for a high efficiency industry had been developed by 1900 and it is the preceding 150 years which display those factors which determined that copper would become the major wire product that it is. By the beginning of the 20th century, copper wire was an essential material, found in almost every device and installation known to the electrical industry. It had almost completely ousted its main rivals, steel and iron wire, both of which, at one time or another, had achieved a far wider

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- 1 Brown N. & Turnbull C. A Century of Copper. Effingham 1900, Part 1 p. 20 and 81.
- 2 About 1890.
- 3 Jewkes J., Sawyers D., Stillerman R. The Sources of Invention. Macmillan 1969, p. 320.

degree of acceptance for certain electrical applications in competition with copper. It is remarkable therefore, to consider that most probably steel, iron and copper wire would be produced on basically identical machines in the same wire-mill; this is a comment on the need to consider how the general wire-drawing industry developed to conform with those demands made upon it by the necessities and needs, requirements and criticisms of other trades and industries. Indeed, the retention of copper wire manufacture within the general wire-drawing industry indicates too the necessity to understand fully those factors which were the pre-requisite for a trade that centred itself upon copper and copper wire. The facilities for production, the market demands for a particular wire product, were complementary factors each stimulating the other. However, the growth of the copper wire industry, and the facilities to generate that growth are at times difficult to establish and become matters of fine distinction. Nonetheless, those tenuous and indistinct factors which often provided momentum for an advance in the copper wire industry were, up to the 1880's, tied to the pattern due to the mutual stimulation of supply and demand - improved markets, improved manufacturing methods and improved products; and it is in the circular relationship of these factors that establishing antecedence becomes difficult. Consequently, advances in the industry require considerations of major inventions in wire-drawing machinery, the growth of other arts and industries, the rise and advances in physical and electrical science and the implementation of prime movers etc.

We are presented therefore, with a series of pertinent questions. If we are to look at the production of copper wire during the rise of the electrical industry, we must also aim to answer a number of queries about the condition of the wire industry not only during, but after, the rise of electrical science and engineering. We must ask what were the traditional roles and applications of copper wire and how did its markets change? How did the organisation of the mills and companies making copper wire evolve and what special circumstances helped to ensure their development? What factors determined the technical developments of wire-making and how did copper wire come to be preferred for electrical practices? In short, we need to search out the economic, technical and social pressures that determined the formation of an industry, but in doing so we are looking principally at the external influences that were prominent in producing change. The impetus for change was not however always external and an investigation such as this must seek to understand something of how the wire manufacturers themselves, played a part in controlling their own progress. It is reasonable to ask, for example, if the wire industry itself did much to foster new markets, or attempt to influence its prosperity by technical or organisational improvements. Indeed, it should also be asked if it actively went about making its products more fitting to the future needs of the consumer or did it simply run parallel to the technical demands of the day? Further, how did the wire industry react to the conflicting demands which appeared to force a choice between traditional markets and production methods and the new areas of consumption, which though promising prosperity required risk in the investment of new and technically

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more difficult processes. Finally, given that the wire industry did mature into a self-contained, organised and flexible manufacturing facility, it must be asked if this was principally because it fulfilled the needs of traditional and conventional markets, or because it had the capacity to make available commodities which, by virtue of their advanced properties, made practicable other technical projects, hitherto impossible? Were these, or similar reasons, responsible for the failure of a separate and distinct copper wire industry to appear? (As will emerge from the following chapters, the wire industry was reluctant to fragment or over specialise even though it had opportunity and reason in the vast new applications of electricity).

As previously asserted, the subject of this work is one much neglected and necessarily involved with many of the technicalities of wire-making. In view of this, it is convenient at this juncture to turn first to an explanation of the plan and structure of this thesis, and then to consider the literature and data upon which it is based.

To provide some insight into the origins of an organised wire industry, and so as to allow the proceeding chapters to concentrate upon the fortunes of copper wire, the first chapter deals with the history of wire-making as a general theme and concludes its course about 1750. Hence, within the three main sections comprising Chapter 1, the manufacture of wire is considered from antiquity to a time when the first industrial changes of real consequence to the manufacture of copper wire, were detectable. The value of this approach, and its justification, lies mainly in the fact that in dispensing with the background and the technicalities of wire-making in the early pages, we can see and understand so much the better the significance of the manifold influences that were to control the production of copper wire. As far as this is concerned, Chapter 2 extracts the early history of copper wire and provides a proper introduction into the main theme of the work (Chapter 3) which begins with the circumstances surrounding the early periods of expansion in copper wire markets. As a final word on the first chapter, it may be remarked that it provides a concise interpretation of the history of wire yet with an adequate depth of study. Indeed, this section contributes to our knowledge of the history of wire, particularly when dealing with early machines, processes and production methods.

As stated, Chapter 3 is concerned with the expansion of markets at the onset of the first industrial revolution. Chapter 4 continues this theme and gives, as far as is possible, answers to many of the questions which relate to the organisation of the wire-mills and the new and traditional non-electrical applications of copper wire. At this appropriate point, Chapter 5 begins a series of four chapters (Chapter 5, 6, 7 and 10) which concentrate on the ascent of copper wire as an electrical conductor. Here, the passage of traditionally made copper wire to its becoming a product manufactured as an electrical conductor is detailed, as are the attendant problems that had to be overcome. With regard to the internal activities of the wire-mills and wire-shops of the period, mention is made throughout the work, but more especially in Chapters 8, 9 and 11, which concern themselves with the operational

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and organisational aspects of the wire industry during and at the end of the 19th century. In addition to the above, there are included two appendices which, though of a different character, address themselves to the subject and which, I feel, are of some importance. Appendix 1 is concerned with the trading statistics of copper wire in England during the 19th century; it provides a graphic illustration of, and the evidence for, the general increase in the consumption of copper during that time. Appendix 2 is of an unusual nature in that it describes a series of tests on some of the copper wire used by Michael Faraday, the results serving to support a good deal of the written evidence cited in the text. Having now broached the subject of the literature relied on in this work, it is a convenient point to briefly consider the sources upon which this investigation is based.

Sources and Bibliography

There appear to be few prior monographs dealing with wire, and seldom has any attempt been made to systematically assess its past history. Though K. B. Lewis is said to have written a comprehensive history of wire sometime about 1932, a copy is not forthcoming. Probably the most abused of all works, with regard to the history of wire, and here the author must add his name to those that have leaned upon it, is J. Beckmann's *History of Inventions and Discoveries* (4 vols., London 1814) the English edition of his *Beitrage zur Geshichte der Erfindungen* (1780-1805). Beckmann's treatment of wire comprises but a small part of an extensive work dealing with a multitude of subjects. Nevertheless he was, it seems, the first to take pains in an attempt to chart the history and development of wire with anything like a scholarly attitude. Unfortunately this work, so dependent upon literature, while making it still an excellent source to draw on, has paled a little in the light of modern research which has the additional advantage of artifact and electron-microscope. (I refer here to a number of recent laboratory investigations into samples of wire from antiquity, but this point will be pursued later). So learned and respected was Beckmann's work that we find it, in one form or another, in almost every literary mention of wire from the time he first published; occasionally extracts are verbatim et literatim, sometimes rephrased (but instantly recognisable) and seldom acknowledged. In mitigation, many of those works dealing with wire that began with the theft of Beckmann's efforts conclude with contemporary accounts of wire-making and thus for each era one can take cyclopaedia and encyclopaedia, lexicon and general engineering treatise and often find out the past history of wire, by courtesy of Beckmann, followed by a reasonable account of the current state of the art. Contemporary accounts of wire-making are generally the most enlightening sources available, even though the majority neglect to say anything about the antecedence of some of the peculiar processes they describe. In this area the range of literature is sufficient but less than abundant and tends to be sparse in detail, generally containing the subject of wire in a few words and without elaboration. It becomes then a matter of taking one detail from one particular source, questioning it and comparing it and then adding what is left to the information gleamed from elsewhere. Typically, from Houghton (*A Collection Toward Husbandry and Trade*

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Vol. 11, London 1697) we find something on the English wire-mills and their use of French draw-plates, from Piringuccio (*De La Pyrotechnia*. Venice 1535) we glean a little more on the subject of draw-plates and come to know much more of 16th century wire-drawing machines. From Hesus (*Urbs Norinberga*. Nurnberg 1532) we learn something of the origin of the first self-acting wire-drawing machine and note from Diderot (*Encyclopaedia* - Dover 1959), Du Hamel (*Art de Metiers - Art de Reduire le Fer en Fil*. Paris 1766) that similar machines are still common in the 1760's. More suprisingly, as we trace the progress of wire and its technology, we find that the vestiges of early methods are still to be found up to recent times; the use of the swing as a means of carrying the wire-drawer while pulling is still in use as late as 1806 according to Charles Heath (*Historical and Descriptive Account of Tintern Abbey*. Charles Heath 1806) while Joan Day in her 'Bristol Brass' (David and Charles 1973) describes machines still in use earlier this century which bear every resemblance to machines in use some 200 years ago.

Having said something about the development of wire technology in general, let me now turn to the principal area of interest for this study and consider the sources that tell something of the rise and history of copper wire and its manufacturing industry. It should be said at the outset that the acquisition of sources, both primary and secondary, was essentially an exercise in sifting. Some of the sources that provided information about the general wire industry proved most useful also in adding to the information specifically on copper wire. The one treatise on wire that took a general view of the appearance, structure and products of the wire industry at the end of the 19th century was Bucknall-Smith's *Treatise on Wire*. (London 1891) which, along with F. A. Perrin's *Conductors For Electrical Distribution* (Von Nostrand, New York 1903) gave a fair insight into the state of copper wire manufacture during the last third of the 19th century. Indeed, their work echoed the practices common to most of the 19th century and along with a number of other sources, many and varied, a fairly complete picture of 19th century copper wire manufacturing technology and its industrial organisation, could be built up. For the period before 1800, probably the best secondary source is Henry Hamilton's *The English Brass and Copper Industries to 1800* (originally published in 1926 but re-printed by Cass in 1967). Hamilton's investigation is detailed and scholarly in its review of the organisational changes which occurred in the brass and copper industries up to the beginning of the 19th century. Within the pages of his work are to be found a few, but very valuable, references to companies trading in copper and copper wire. However, Hamilton's work has some weaknesses, especially in its interpretation and understanding of certain technical matters (for further comment on this, see main text). With regard to this it may be mentioned that modern works too can be a source of inaccuracies and discrepancies. One must be wary of those extensive works which purport to be "Histories" of technology. Overall, these works tend to be excellent but are prone to serve the subject of wire quite badly; Singer et al in their *History of Technology* (5 Vols., Oxford 1954-8) include two howling inaccuracies when talking of the "iron wire" used as conductors for the cross-channel and Trans-Atlantic cables of 1850 and 1857 respectively (in both cases

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copper conductors (wire) were used).

The bulk of the material in the ensuing script depends heavily on what can be squeezed from contemporary and modern research papers and private correspondence. Enquiries ranging from correspondence with research departments in the British Museum, to a pain-staking examination of the scientific papers of individuals' who made a serious contribution to improvements in copper wire. In general, this has been the best, and often the only way to acquire the technical details which were important in the development and change of copper wire, from being a traditional staple commodity to an entirely different thing, an electrical conductor. The technical journals were found to be extremely useful. The journals of the Institute of Civil Engineers (from 1852) and the Society of Telegraph Engineers (from 1871) provided invaluable information as did the various volumes of the Proceedings of the Royal Society and the periodic publications of the Philosophical Magazine. A host of other periodicals, of various natures, either technical or non-technical, have added information also.

Turning now more fully to the individuals who figure in the development of copper wire, the standard works of reference have been found indispensable. In selecting those people to be discussed in this work, I have tried not to bring in anyone who did not stand prominently in some part of the history and development of copper wire and its industry. Though I have tried not to overlook anyone recognised as having contributed, recognition is in this instance a value judgement and is necessarily subjective and determined by the limitations of a work such as this. In short, those that have been overlooked, are ignored simply as a matter of space. However, for those individuals that do find a place, the Dictionary(ies) of National Biography, excellent though they generally are, are often deficient in their degree of detail and sometimes greater insight has been achieved by taking note, where possible, of the correspondence of those that stand in the history and ascent of copper wire either as a subject of scientific investigation or as part of a general enquiry. The correspondence of Ezra Cornell (Department of Regional History, Cornell University) and William Thomson, 1st Baron Kelvin of Largs, (Kelvin - Stokes Collection, Department of Manuscripts, Cambridge University Library) will be found, as too that of others. Some regret must be expressed in the fact that part of the Thomson correspondence now appears lost. Certain letters referring to his role in the production of the 1857 Trans-Atlantic telegraph cable are cited by Silvanus P. Thompson (Life of Lord Kelvin, 2 Vols., Macmillan, London 1910) but since that time the papers seem to have gone astray. Certainly, the correspondence is known to have resided at the Cavendish Laboratory Library up to the time when Thompson examined them; where this material is deposited now, or if it still exists, is not known. Unfortunately, these letters, and we can only trust S. P. Thompson for what they contained, play a most important part in maintaining the historical continuity of those sections in this work dealing with the production of the early submarine telegraph cables. As such, Thompson's

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bibliography of Kelvin becomes just short of crucial in this work. In their reproduction by Thompson, the letters of Kelvin become essentially primary sources derived from what remains a secondary area of information.

Since it is outside the scope of this introduction to include a full and critical bibliographical essay (which would probably extend to a length far beyond the present offering) it is hoped that this brief and somewhat superficial revue will suffice. As a last word therefore, it should be stressed that the fine differences which can exist in classing a source primary or secondary can become an elaborate and wasted argument. As noted above, in many instances the value of a reference lies in its availability and not necessarily its credibility - often patently secondary sources remain the only ones we have. Hamilton, for example, had access to material before the war and before bombing, and the neglect of company archives in the ensuing years of change, could have resulted in them being lost forever. Thompson too refers to certain letters of Kelvin, though now apparently lost we cannot deny that they once existed. Similarly, R. B. Prosser (*Birmingham Inventors and Inventions*, Birmingham 1881) had access to sources in the Birmingham Public Library which, following the fire of 1879 are now denied us. Patents too, used extensively here as a source of technical literature, describe manufacturing processes in an age when technical literature can hardly be said to have been common. Yet these very patents are often coloured to inflate the value of the invention or process. Without alternative and comparable descriptions of the same or similar techniques, we must take what is written as the case. However, this does not deny the need to remain prudent and wary and to apply critical interpretation in the use of such material. Since no source can be considered absolutely precise, or to supply every detail unambiguously written, the problem becomes that of analysis and translation. This, however, being a subjective quantity dependent upon the technical expertise of the reader, runs the risk of misinterpretation. The selection of sources of information, where problems of interpretation becomes reduced or unnecessary, should therefore assume paramount importance. Such opportunities, it is admitted, seldom occur but the author has taken the view that one illustration or perhaps one electron-micrograph is worth ten thousand words. Wherever possible then, this work bases itself upon technical investigations which can support the available literature by supplying substantive material evidence. An example of this is the author's investigation into the copper wire used by Michael Faraday (see Appendix 2). This investigation proved particularly useful in confirming wire quality, methods of manufacture and applications for the early 19th century, and yet had implications beyond its supportive role. Likewise, the papers by D. L. Carroll (*American Journal of Archeology*, 1972) give similar evidence for wire-making in antiquity. Along with the detailed bibliography, the reader should note also the list of sources given with the pictorial and illustrative material which accompanies this work.

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In exploring the rise of an industrial effort based on copper wire, this work highlights the simple fact that the history of copper wire appears complex because of the diverse application of copper wire. The manufacture of copper wire became the manufacture of a staple commodity; a commodity which was continually being adapted for special purposes. It was the success of these special purposes (appearing periodically) which acted to influence, mould and stimulate the growth of the wire mills and determine the path along which they would evolve. Special purposes grew

into established uses, the demise of one application saw the birth of a new, and often bigger one. As with other staple items of manufacture, its simplicity was its virtue and its growth due to the growth of other industries.

The most influential series of circumstances affecting the manufacture of copper wire was the rise in telegraphy, telephony and power transmission, the first named being an area which, in its infancy, called for copper wire in a traditional form. As matters developed, a demand for improved copper wire, to meet more stringent electrical specifications, effected improvements in wire, but only slowly. The wire industry was ill-equipped to answer the needs of electrical science overnight. Progress came slowly but eventually resulted in the wire industry, itself, presenting its consumers with improved products, which by their nature fulfilled outstanding deficiencies in transmission lines and electrical conduction. Whereas, initially, electrical science influenced the wire industry, it was later to be that the wire industry was able to guide electrical science and engineering.

The history of the evolution of the copper wire industry is both fascinating and enlightening - it is also however, in part, the history of the general wire-drawing industry, the telegraph and submarine cable industry and the electrical industry; of inventors, scientists, individuals of different sorts and of capitalists, companies and combines. But, above this, it remains a history which expresses the careful, cautious path taken by what became an essential, and eventually highly successful manufacturing concern.

Not every area of this work is given as complete or as detailed a treatment as it deserves. The sheer weight of the task of breaking new ground makes this impossible. Nevertheless, those parts which are sparing in their consideration will, it is hoped, provide inspiration for later work.

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CHAPTER 1

WIRE MAKING TECHNOLOGY

It seems probable that the malleability of certain metals was discovered before their ductility. The operation of cold working a metal with a hammer, and changing its dimensions - from cast bar or plate to sheet - necessarily preceeds any other when hand-working metal, and it is a natural progression within this exercise to turn sheet into a rod by the same means. This technique, therefore, is almost certainly the first method which might be described as wire-working. The sheet, if thin enough, could be turned and folded in on itself and hammered flat. The repeating of this process would produce a long quadrate of various dimensions depending on the original width of sheet (or block) used. Abrading each corner of the rough rod, with stone or file would eventually produce a round rod or length of wire. We find a like process in Exodus XXXIX v 3:-

"And they did beat the gold into thin plates,
and cut it into wires, to work it into the
blue, and in the purple and in the scarlet¹
and in the fine linen, with cunning work."

This biblical extract which is the earliest description of wire-working, describes an alternative and probably improved technique of cutting plates (or sheet) into wire. This by definition is an advance on the technique described above, because the cutting of the metal would seem to be clean enough to allow its direct working into Aaron's Sacerdotal dress. It is not clear if any other process was used after the sheets were cut - we may presume that some polishing, but more likely stretching, took place.

Some authorities, for example Higgins,² have indicated that an intermediate process (that of first rolling the strip, or slips, between heavy, flat, stone or metal plates to round it before - and if - the wire was to be stretched) might have been used. This would

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- 1 The value of this work throughout the ages of fashion is well documented and the art survives to this day. Its importance, as an industry in its own right, is in evidence through much of the history of wire making. (Vide supra Chapter 1 p. 34) Vitruvius (Marcus Vitruvius Pollio) circa 50 BC, writing in his treatise 'De Architectur-Libri Decem' (Book 7 Chapter 8) describes how red lead may be used to recover gold from worn out embroidery as described in Exodus above. See also the Encyclopaedia Britannica 13th Edition (Chicago University Press) 1926 Vol. 28 p. 150.
- 2 Higgins R. A. "Greek and Roman Jewellery" Methuen & Co., London 1961 p. 14-17.

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certainly be conceivable for some of the more ductile-malleable metals such as gold. In this context therefore, it does not seem inconsistent with the period, and that process, described in the above. The part of Exodus in which Aaron's dress is described, is that part written by "P" - one of the three contributors. It is believed that the period described is about 580 BC¹ so we may assume that the wire making in Exodus dates from this time. However, it may be that such a technique was retained only for very ductile metals such as gold,² which could be cold worked easily and that wire manufacture in other metals had a different and possibly inferior technology. Lewis, writing in 1936,³ suggested further that both the metals, gold and silver, could be formed into wire by eliminating all stages of hammer work other than the forming of beaten sheet. In this instance, the sheet would be rolled up as tightly as possible and then dragged through a series of holes, punched through either wood or metal, so as to roll it tighter. When the resistance became too high (as the 'rod' was passed through) the operation would be complete. Lewis claimed to have samples of early wire in which it was possible to push a human hair into the minute orifice left by rolled (folded) metal in the middle of the wire. Microscopic evidence indicated also the 'polishing out' of the foil edge along the length of the wire. This technique is arguably wire-drawing, rather than 'wire making' and more primitive techniques were generally associated with wire working in other metals. The cutting of the sheet metal into strips⁴ is only one stage removed from cleaving a block or rod of metal with a chisel⁵ (or axe head) to produce a strip. Consequently, the method of taking cut, cleaved or folded strips of ductile metal and pulling them into wires must be considered as one possible technique which preceded any other besides that of forming wire directly.

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- 1 Article - Exodus (Vol. 10 p. 77) and Bible (Vol. 3 p. 852) Encyclopaedia Britannica 13th Edition op cit.
- 2 This is probably why cast pins or wire are such a rarity.
- 3 Lewis K. B. "Wire Beginnings" Wire Industry Vol. 3 No. 25 (1936) p. 5.
- 4 With a cutting tool - chisel, shears or files - or ripping along a clamped edge.
- 5 Vide supra Chapter 1 p. 35 - an axe head and a chisel, as a tool, are not far removed.

with a hammer. The stretching of a strip of ductile metal reduces its cross sectional area and this is tantamount to drawing the strip through a constriction to shape it into a wire, but it may be applied to only the most ductile of metals. The method for working gold would differ to those methods used to form wire of copper or bronze, both of which are materials malleable only when heated, or heat treated.

Although F. L. Griffith claimed that in ancient Egypt "thin wire was hammered out but there is no ancient instance of drawn wire",¹ it is possible that a method developed by the Egyptian engravers and sculptors enabled wire-drawing to begin, possibly in the 2nd or 3rd millenium.² These artisans had adopted a technique used in pre-historic Tiryns - a copper blade with teeth of emery (a fragment of which has been found in a saw-cut) was used for cutting hard stones; by making tubular copper drills³ aided by emery powder (plentiful in the Aegaens) this same method allowed holes to be bored into stones.⁴ In this way, a primitive, but effective draw plate (draw-stone)⁵ might be fashioned, the metal-worker would roll the tube of copper between his hands onto a thin but wide slab of hard stone. The two faces of both the stone and copper boring tube would be spread with emery - after some time the stone would be worn down and holed.⁶ It is interesting that the copper tubes were probably made from the same sheets used to make wire (or the

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- 1 Article - Egypt (Ancient Art) Encyclopaedia Britannica op cit Vol. 9 p. 73.
- 2 "But that is not all in the Kings Library: There are other things to be seen - A Sistrum or Egyptian rattle with three loose and running wires cross it" Lister Dr. Martin. A Journey to Paris. p. 111. Jacob Tonson London 1698.
- 3 Copper tubing was current in Egypt about 2750 BC. See An Introduction To Copper. C.D.A. publication 1957 p. 3 - It was probably made by laying a mandrel on a metal sheet and driving the sheet into a groove cut in wood or metal. Alternatively, it was made by wrapping sheet around the mandrel with hammer blows.
- 4 Petrie Sir Flinders. Ten Years Digging In Egypt. 1893 p. 25-27. See also Ancient Egypt. 1927 p. 58.
- 5 A rod of metal would be hammered into a rough rod shape initially and then drawn through the stone.
- 6 It is worth considering the Neolithic, so called, "age of polished stone" - many axe heads are found highly polished and with holes or sockets bored through the middle for a shaft (hafting). The transition, of stone axe head, to that during the Bronze age resulted in the puzzling and curious situation of the early failure to incorporate a shaft socket in the axe heads (celt) though the Stone age method has survived till today through a re-evolved redevelopment of the shaft hole at the latter end of the Bronze age which saw the appearance of a hafted celt. (See Read C. H. on "Archeology" Encyclopaedia Britannica 13th Ed. op cit Vol. 2 pp. 348, 352) It is possible that early Bronze age casting techniques were without a solution to the problem of forming a mould whereby a hole could be cast into the head of the blade.

copper utensils that proliferated) before or during the Bronze Age in Egypt. By the advent of the Egyptian iron age, the three possible ways of making wire, forming with a hammer; forming by rolling and stretching; and drawing through stone had probably all been discovered. A method which combined much from all three categories has been described,¹ and this appears to answer questions about the manufacture of wire artifacts (from antiquity) not easily explained solely by the methods outlined above. Wire-making by 'strip-twisting' and 'strip-drawing' has been proposed where in the first method, the wire is formed by taking a 'slip' of metal cut from a beaten sheet and twisting it until the overlaying edges meet and form a rough 'spiralled' wire. The resultant thread is then rolled between heavy slabs of flat stone, to smooth out the surface of the wire. 'Strip-drawing' consists of taking a 'slip' of thin metal, as in 'strip-twisting' and pulling it through a stone, copper or iron 'draw' die. It is claimed that 'strip-drawing' requires very little effort in comparison to the drawing of a solid rod - the 'slip' is progressively formed by successive reduction through smaller and smaller holes and as the size is reduced, the two edges of the 'slip' fold into one another and overlap. Ultimately a wire forms, and experiment has shown that gold can be drawn holding a draw-plate in the hand. The effort is so slight that, for this reason, draw-plates can be made of those 'softer' metals, copper and soft iron, known in early Egyptian, Hellenistic and Roman times. Annealing between reductions tends to promote an even easier task.

The techniques described above can be seen to have an advantage over hammer-worked wire in terms of reduced labour and an improved product. Examples of all techniques described above may be cited in items of jewellery made in antiquity.² It should be stressed however, that hammer work was favoured for copper and bronze; evidence from artifacts reveals that for the less workable metals 'strip-twisting' and

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- 1 Carroll D. L. "Wire Drawing in Antiquity" American Journal of Archeology Vol. 76 1972 p. 321-323.
- 2 Carroll D. L. "Drawn Wire and the Identification of Forgeries" American Journal of Archeology Vol. 74 1970 p. 40 and Plates 69 and 70.

'strip-drawing' were uncommon. Gold and silver however, answered well to these techniques.

A large number of other archeological finds have also indicated that these techniques were responsible for the manufacture of a wide variety of articles at various times. Of those incorporating wire or wire-rod, a few are worth mentioning. Both the first and second cities of Troy, after excavation, have delivered up copper wire articles that are of great interest. Copper rivets¹ and almost pure copper nails (weighing 2½lb) have been discovered.² Further, as early as 3000 BC, pins were manufactured at Vasilia³ in Cyprus and though not of pure copper (between 2-4% Arsenic) the excavation of these items indicates the fact that the copper-smith understood that hammered copper made wire for pins that did not break easily. Indeed, it was far more attractive than thorns or fish bones for holding clothes, since it could be made to clasp around an ornamental band, making a pleasing safety pin - a brooch or fibulae.

The hammering of copper, to make it hard (by work hardening), and the heating or annealing to soften it, are doubtless methods associated with the ancient crafts which discovered them in the course of producing objects and articles for everyday use.⁴ An understanding of these simple effects provided a method of working on copper that admitted to many variations of article and use. This being so, the artisans of metal armed with a certain understanding of alloying, and a knowledge of achieving desired properties in metals by alloying, heat action or mechanical deformation, came by their expertise through familiarity with the material. The progression in metal working, therefore, came by empiricism and very surely allowed parallel advances in smelting and refining other ores.

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- 1 Gowland W. "The Metals In Antiquity" Jrn. Roy. Anthropological Inst. Vol. 42 1912 p. 247.
- 2 Gowland W. "Copper And Its Alloys In Early Times" Jrn. Inst. Metals Vol. 7 1912 p. 35-36.
- 3 The Department of Antiquities at Oxford (The Ashmolean Museum) possess also some fine copper pins found at Vounous in Cyprus. They are circa 2000 BC and appear to be stretched and hammered wire.
- 4 Aitchison L. History of Metals. 2 Vols. MacDonald and Evans 1960 Vol. 1 p. 214

With the coming of iron, it was possible to manufacture superior weapons and tools and, in part, dispense with the copper and bronze for everything other than the more ornamental articles. No real chronological value is afforded by the terms Stone, Bronze and Iron ages - there was really no universal or global synchronous sequence of the three epochs¹ - parts of the more advanced civilisations enjoyed a combined Bronze and Iron age. As a result, by the 5th or 6th century BC, the Persians were making use of iron draw-plates² and this superior method of wire-drawing was later found in the civilisations of Thrace, Rome and Scandinavia. The plates were perforated with various sized punches when hot and enabled wire to be drawn of iron, bronze and gold in diameters ranging from .02 to .033 (approximately 25 to 21 S.W.G.).

At Pompeii, buried about 79 AD, cables made of bronze wire some 15 foot long and .3 inches in diameter were excavated. Each cable had three twists, each containing 15 strands of bronze wire.³ Some dental treatment in ancient Rome was made possible through the use of gold wire, which was used to fasten a loose tooth or implant one of ivory. Either one of the remedies was based on binding, by way of the wire, the affected tooth to the next one.⁴ One might expect this grade of wire to be of a consistent and suitable diameter for the task. Of greater importance though, would be the quality of the wire surface - smooth and polished, for a draw-plate of iron an easier task.⁵ Less work and thus an efficient, and probably more uniform product, was possible with an iron draw-plate in contrast to wire made by hammering, stretching or rolling.

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- 1 Articles "Bronze age" also "Iron and Stone (Neolithic) age" Vol. 4 p. 640 and Vol. 14 p. 800 Encyclopaedia Britannica 13th Ed. op cit.
- 2 While Aitchison and others such as Derry and Williams (who use Aitchison as a source) are prepared to state this as a matter of fact, some authorities would prefer to place the draw-plate as late as the 1st century BC (i.e. Russel Robinson) and do so on positive evidence such as archeological artifacts, rather than by way of a retrograde analysis which traces the history to an earlier period through other types of evidence. Vide supra Chapter 1 p. 13.
- 3 Neuberger A. The Technical Arts and Sciences of the Ancients Trans. H. L. Bros Mathuen & Co., London 1930.
- 4 Beckmann J. History of Inventions and Discoveries J. Walker & Sons London 1814 Vol. 2 p. 222.
- 5 Vide supra p.13 et seq. Wire drawn through a draw-plate became known as "bright drawn" whereas metals otherwise treated i.e. rolling or hammering and stretching usually had no designation, but sometimes were referred to as 'black' e.g. "Black Latten".

Iron draw-plates allowed successive reduction quickly and were relatively easy to produce, compared to the arduous task of grinding a hole through stone which, in the end, resulted in only one fairly unwieldy draw orifice. One problem was that a stone could prove very difficult to mount in anything, or in any way, that clamped it sufficiently for the task of drawing wire through it. It is however this, which appears the principal disadvantage. As has been shown by numerous excavated examples, a high polish with excellent uniformity was possible in Stone age work and it seems that had a Neolithic craftsman the interest and intent of making a stone draw-plate, then he certainly could have produced an almost ideal implement. However, it seems reasonable to suppose that by the time metal wires^{*} were utilised and incorporated into early metal working, the art of stone work (of such excellence) had been lost. Thus, by the middle Bronze age, the technique of manufacturing stone draw-plates had to be rediscovered. Moreover, much depended on whether or not the right kind of stone was available in a locality - sandstone for example, would have been useless in this respect.¹

Unlike the iron draw-plate, the stone could not be quickly penetrated by a simple punch which, by varying the diameter, could implement a draw-plate carrying a succession of holes, each one progressively smaller, allowing a range of wire diameters to be produced. Indeed, if the first hole in the draw-plate was made big enough, little re-shaping was required of the first strip (or slip) of beaten metal sheet and this facilitated jointing of one strip to another to make long lengths of wire. As the strip was pulled through the draw-plate by pincers or by wrapping it around a leather wrist band, the end would not be completely cleared from the orifice. At this point, previous to the discovery of soldering, a new strip might be riveted into place, but by 30 BC or earlier the long-known metal, lead,² was being used to solder strips of copper together - other

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- 1 It is a matter of some regret that it is very difficult to determine whether a drawn wire was formed in a stone or iron draw-plate. Except for surface contamination of say iron on copper wire, there is likely to be no other indication of the type of draw-plate. Iron, for example, would be indistinguishable in surface properties had it been drawn through stone or iron.
 - 2 Pliny the Elder, knew the material in two different forms - *plumbum nigrum* and *plumbum album* - however they appear to be lead and a lead tin alloy used for soldering i.e. a black and silvery white form of lead. Pliny "Naturalis Historia XXXIII Sect. 3-19.
- * Though scant evidence exists for iron wire in this period, this on the whole is not surprising, considering the change in climatic conditions that occurred - the dryness of late Neolithic and Bronze age times was replaced by increasing dampness. The iron would be unlikely to survive the erosion of millenia.

soldering alloys in use were those composed of the five commonly known metals, gold, silver, copper, lead and tin,¹ and from these metals, brazing and soldering materials were derived. Copper was soldered by an almost modern lead-tin alloy and examples of gold-copper and silver-copper soldering is in evidence, according to Aitchison. No doubt, these solders would have been available in the form of rod, tape or wire - a necessity purely from the point of view of handling, especially for the delicate work of the silver or gold-smith, who would joint with electrum, silver-copper or silver-tin. Other techniques would have required a powdered metal hence the joining of two "wires" for lengthening in the drawing stage, would have been accomplished by overlaying two strips that sandwiched small cuttings of copper and tin. The application of heat fused the two strips as the cuttings flowed. For good measure, a rivet would be driven through. This rivet could have been bronze or copper - itself a product of the wire-makers craft.

Whether or not the ancients applied some form of prime-mover to wire-drawing is not known; though it is doubtful that wire-making was carried out other than by purely manual techniques, water power may have been utilised.² The fragmentary evidence which is the basis for the earlier descriptions of ancient wire-working, implies that geographic factors and circumstances were on occasion, necessary for a degree of sophisticated wire technology. It would seem that the ideal conditions, where a plentiful and easily accessible source of metal (copper or iron ores) was available - furnace and smelting technology, plus the art of metal working along with drawing through good hard stone dies (where the art had not been lost) - would constitute the pinnacle of ancient technology. Such a time in the right locality may have occurred, perhaps at the middle of the Bronze and at the beginnings of the Iron ages in some of the Mediterranean

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- 1 These metals were identifiable as early as 590 BC - see Ezekial XXII 17-21. The King James Biblical Text refers to "Brass". This name is, in reality, what today we know as copper - whilst the zinc-copper alloy we call Brass was at the time of King James, known as Latten or Lattin.
- 2 Vitruvius is able to describe water-wheels and complex water-drum machinery as early as 50 BC. See Bernal J. Science in History. Pelican 1969 4 Vols. Vol. 1 p. 314. Also Vitruvius. De Architectura -. Book 10 Chapter 1, 4, 6 & 7. (Loeb 1931-4).

civilisations. We may regard the use of water power in such a scheme as possible, albeit improbable.¹

This idealised set of circumstances is a construct which consists of the important components that were discovered, (or lost and re-discovered), to form the ultimate wire-drawing technology for those early times. However, as has been said, it is improbable that all the factors coalesced anywhere at any one time. Hammer forging of wire would have been practiced where impurities in the smelt (arsenic, phosphorus and sulphur) might have made an alloy insufficiently ductile for drawing. The same would have occurred where smelting and forging techniques themselves, were poor such that iron for example could not be processed. If the stone draw-plate was a lost art in such circumstances, then only bronze or copper would have been available for metal working by twisting, stretching or the hammer. A number of like circumstances may be considered, as too a variety of permutations.

Whatever the manufacturing constraints, superb examples still exist of early metal working in both the base and noble metals - some, which are wire products, have been quoted and items such as copper rivets, nails and rod, bronze fibulae and gold filigree are reminders that the uses and requirements of wire in ancient times were many.

While admiring such works as these, it is worth reminding ourselves of the contrasting times in which they might have been produced. Thus, in considering the disdain with which many Greek and Romans held technology, it is not suprising (or perhaps it is) that metal working in general, and wire working in particular, lost and rediscovered methods and techniques. Xenophon (circa 430 BC) stated certain Greeks' attitudes in

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1 The two great ancient mechanicians who might have achieved this - Archimedes (287-212 BC) and Heronis Alexandrias (Hero - first century AD) were much later than the period imagined, and since we have nothing from Pliny, Plutarch, Livy or Vitruvius on such matters, it would appear that the possibility is remote.

no uncertain terms:-

"What are called the mechanical arts carry a social stigma and are rightly dishonoured in our cities. For these arts damage the bodies of those who work at them or who act as overseers, by compelling them to a sedentary life and to an indoor life, and, in some cases, to spend the whole day by the fire. This physical degeneration results also in deterioration of the soul. Furthermore, the workers at these trades simply have not got the time to perform the offices of friendship or citizenship. Consequently they are looked upon as bad friends and bad patriots, and in some cities, especially the warlike ones, it is not legal for a citizen to ply a mechanical trade."¹

This attitude remained consistent through the Greek civilisation, some 200 years after Xenophon, it was to be said of Archimedes that he:-

" - set no value on the ingenious mechanical contrivances which made him famous, regarding them as beneath the dignity of pure science, declining even to have a written record made of them."²

And though Derry and Williams³ conclude much the same of the Romans (who depended heavily on foreign immigrants for technical advances) this serves only to highlight exceptions, such as Vitruvius. It is perhaps the lack of intercourse between scholar and craftsman that contributed also to the erratic history of early wire technology as described above, and it is arguable that the legacy of insular Roman and Hellenistic science was to impede technology for many centuries - science (and consequently technology in part) was shackled with the chains of Aristotelian dogma up to recent times. Though men like Pliny might describe its products, the art of wire making gained little in invention or ideas from his kind.⁴ Thus, at the decline of the unified Roman Empire

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- 1 Xenophon. *Oeconomicus*. Vol. IV, 203 - reprinted from Fowler W. S. *The Development of Scientific Method*. Pergamon London 1962 p. 21.
- 2 Heath T. L. "Archimedes" *Britannica* 13th Ed. op cit Vol. 2 p. 368.
- 3 Derry T. K., Williams T. I. *Short History of Technology*. Oxford 1970 p. 22.
- 4 It is, strangely, Pliny who mentions other lost arts - at the end of the section, in which he deals with "caelutura" - dealing with the works of Greek artists - he claims that certain techniques are apparently lost arts e.g. silver chasing. However, we know now that this is not so. Modern archeological finds of the period confirm a contrary situation. See Pliny. *Historia Naturalis*. XXXIII 154 sqq.

(approx. 300 AD) the upheaval of states, culture and technology that followed in the wake of the Barbarians left a void for many centuries where only a minimum of centres of scholarship would remain. In this time, only a few would chronicle the age and a mere handful only advanced knowledge, while it was to the East that the science and learning of the ancients was to find sanctuary and utilisation. What is known of the ancients is due, in no small way, to the Arab civilisations which flourished during the dark ages of learning in much of the rest of the world. For some ten centuries, there is little known of the development of wire-drawing, for the period 300 to 1300 there was no records equal to those of the untiring compiler, Pliny, and for the understanding of what might have occurred in wire making during, and subsequent to, the dark ages, it becomes necessary to evaluate the scant documentary evidence that is available for those times. Primarily however, it is from the artifacts discovered in archeological searches and the chance findings of remnants, that much is learned.

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THE DARK AGES TO 1350

From the 5th to about the 11th century, Europe saw little cultural progress. As stated in the previous chapter, the final dismemberment of the Roman Empire in the West (476 AD) broke the tradition of communication and the slave societies that could support and foster both an intelligentsia and a developing technology.

It appears that arts and trades, while not improving their relevant technology, could still service those areas lost in the disorganised lands that surrounded Italy. Alaric the Visigoth, withdrew from the first siege of Rome (409-10) after payment of gold, silver and copper,¹ and we may presume that neither one of the metals was lacking in value to him. A deduction follows, in that the availability of copper to the Visigoths, or indeed any of the other tribes at this time was limited, even scarce, and this is not inconsistent with the picture of a disorganised Europe, unstable and prone to erratic boundaries.

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1 Grant M. The Fall of the Roman Empire. Annenberg 1970 p. 39.

Mining, smelting and metal working one may relate to political and social stability to some degree. Such a situation was not to be observed in this period except in those places once comparatively rich in both social and economic stability and not overrun by invaders. So, where the metal workers could still find and process ores, and where the craftsmen could still form the metal and find a market for his wares the crafts and trade would survive; this, the vestiges of the 'Pax Romana' were able to offer. (The stimulus of war in metal working remains only so long as hostilities are outside the industrial localities. Disorganisation follows invasion and the subsequent breakdown of the social order).

We know some of the metal workers capabilities for this time, through stone reliefs that have been excavated. For the black-smith, tools were fairly advanced, the fifth century terracotta relief of a black-smith's workshop (found at Isola Sacra, near Ostia)¹ gives to us an indication of the range of tools in use at the time. Metal sheet cutters are shown, as too is a rounded section which appears to be a forming die for making rod or wire such that a slip, or strip of metal sheet might be roughly shaped by causing it to fold in on itself when pulled through. Further reduction to rod or wire would be contrived by the hammer.

The fact that in Europe, the hammer becomes more important in rod and wire making after the fifth century is given support by the absence of any reference to the drawing of wire by stretching or by use of the draw-plate in any of the few chronicles and annals available for the period. A vague description by Muratori, tells of wire working in the time of Charles the Great (circa 800 AD) but succeeds in informing us only that wire and sheet were formed by the hammer.² No mention is made of wire-drawing by stretching or pulling through discrete dies or draw-plates and since no documentary evidence appears extant to indicate the contrary, it could be concluded that the art of wire-drawing was lost. But it is more likely that this state of events occurred, if at all,

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1 Ibid p. 99.

2 Muratori Ludovico Antonio. *Antiquities Italicae Medii Aevi*. Venice 1743. Ch. 11 p. 397. The reference of importance "de fila aurea facere, de petalis auri et argents". "(The Golden wire, yeilding and easily worked, the thin leaves of gold and silver -)".

only between the 5th and 7th centuries when, in many parts of the world, wire making seems to have regressed to the minimum technology necessary for its production as a consequence of those upheavals in state and culture during this period.

We may infer that such a situation could not stand for long and the appearance of Norsemen warriors using ring and chain mailed *hanberks* as armour, would indicate that from the 4th century AD an advanced art of wire making found refuge in Northern Europe. It is in this area, in the antiquity of Scandinavia, that the earliest reintroduction in Europe of ring and chain mail is found.

It would appear that Thracian mail preceded any other - warriors of Thrace were armoured with plate or ring mail in the 5th or 6th century BC¹ and it seems likely that Scandinavian metal workers harboured the knowledge of it, or rediscovered its advantages a millenium later.² The art of chain and interlocking chain jewellery was known from about 2500 BC³ and it is in this art that the origin of chain mail is to be found. The loop or square chain appears first in Minoan jewellery from about 2200 BC. As expertise increased, in both wire manufacturing and the art of interlinking to produce chains and straps made of discrete links, (either punched out or formed from wire), so the ability to produce mail armour developed until the 5th century, when Thracian warriors had complete coats of wire made mail. Though at this time, the Persian armies fought only lightly armoured, some warriors - those most distinguished by rank or honour - wore mail armour. Since armour was not of a great tactical use to the Persian armies - they favoured decimation of the enemy by the bow and fast thrusts by infantry and mounted troops to produce confusion and division - it is difficult to determine whether first the Thracian or the Persian metal workers invented the technique of chain mail. The fact that Thracian mail appears the more common for this period, indicates a higher

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- 1 From plaques in the exhibition of Thracian antiquities in the British Museum - January 8th to March 29th, 1975.
- 2 Compare the finds in Scythian and Sarmatian graves - one from Zharovka near Kiev contained mail and a Greek Kylix of around the 5th century BC. Its acquisition however, may have been by way of trade or by raiding Celtic settlements.
- 3 Wolley C. L. Ur Excavations. Harper 1933 p. 146-149.

production of wire, but not necessarily the invention of the technique to make it. But, it is likely, that the methods used were Persian in origin. Some evidence that might support this is the excellence with which Persian armourers continued to manufacture mail for at least 700 years after the Thracian culture had ceased to exist. A number of examples exist to support this argument, the remains of both Roman and Persian soldiers were found at Dura Europus¹ and these date to the 3rd century AD, as too does the mail shirt of Roman origin which is to be found in the museum at Saalburg.

Though not absolutely essential (but some authorities would consider it was)² a knowledge of wire-drawing (necessarily) relates to a high volume production of chain mail and vice versa, and it is through the abundance of this armour during the 5th century BC that the invention of wire-drawing, as opposed to wire-pulling or hammering, is placed. How the drawing was carried out is not clearly understood - it may have been stone or iron in use as the draw-die, but it is more satisfactory in terms of the high degree of iron work for this time to favour the use of iron draw-plates. The utilisation of an iron draw-plate is admissible even without the smelting techniques necessary to cast one. As stated earlier, a cake of iron can be worked when red hot and early furnaces of the period were able to raise iron to a workable red heat, from this a cake of iron would be hammered into a thick plate, a long steely punch would produce a rough hole while the metal was still very hot i.e. after being brought to bright red heat. Emery and a bronze file would complete the job of making a neater, more uniform draw hole. Indeed, there is no need to presume that any finishing of any great degree was necessary, since wire drawn through a rough draw orifice abrades the die and tends to clear it, and, in addition, rough drawn wire can, in itself, either be polished or stretched into a wire with an improved consistent surface.³

It can be seen that in fact no high technique was absolutely necessary to draw wire - though casting iron was not to be seen until the early middle ages when furnace

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- 1 The Excavations of Dura Europus. (Preliminary report for session October 1932 to March 1933) Yale University Press 1936.
- 2 Russell Robinson H. 'Oriental Armour. Herret Jenkins 1967 p. 10-11.
- 3 Wrought iron, punched or filed, tends to work-harden at the point of working - the more ductile metals, when drawn through such material, tended to improve the surface by hardening and polishing.

temperatures were raised, it was only to improve the ease and quality of manufacturing draw-plates.¹ Moreover, casting was not the development that heralded mass production of wire in-as-much as it was only an advance in the general metal-working technique. For some two or three hundred years, the knowledge of wire-drawing as a manufacturing technique appears to have been lost. When rediscovered, the old methods were not to be improved for centuries. The rediscovery (or perhaps an expansion of an old art) is traced, as earlier stated, to Scandinavia. The so-called "Baltic Link", the connection between the eastern civilisations and those of Scandinavia in antiquity, indicate that the knowledge of the Persian and Thracian armourers and metal workers found its way, by way of trade or conflict, to Scandinavia. This may have happened as late as the 2nd century AD. The "link" is supported, first, by finds of coins in northern European Celtic communities which originated from Persia - the "Cufic" coins² - and more importantly we may compare similarities between armour such as that used by the Persians and the masked helmet recovered from the Sutton Hoo burial ship.³ By about the 4th century, the Scandinavian settlements were able to provide the stability, that Rome had almost lost, to promote and establish centres where metal workers and armourers could, with their teams of labourers and apprentices, work undisturbed at developing their trades. Production of both weapons, armour and utensils was exacting and time consuming - the ideal conditions, security, fuels, workspace and the availability of ores, was met in the lands of Norway and Sweden. Here, at the beginning of the Scandinavian iron age - approximately 50 BC - the crafts of hammer and draw-plate co-existed in the manufacture of wire. What preference may have existed probably depended on the demands at any one time. The making of armour was probably the most pressing.

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- 1 Chilled cast iron - a very hard material.
- 2 Britannica 13th Ed. op cit Vol. 24 p. 290c.
- 3 Russell Robinson H. op cit p. 10-11. A full appraisal between the connection of the Thracian/Persians and the "Teutons" Celts from the Baltic and the Northern Ocean must include also the migration of these Northern Celts, who originally came from Scandinavia and swept down to produce the Celto-Thracians. The close blood ties between the Celt and the Thracians gives added support to the cultural exchanges of the Thracians and Northern Celts from about the 7th century BC, as does the development of copper working and the discovery of bronze (and later) the working of iron in the Celtic communities in the Alps and Danube valley.

The interlaying of closed iron loops, or the stitching of wire loops in an overlay on leather, as an armour, made demands on the wire-smith, not light in nature. The quantity of rings and loops necessary for the armour of one man would prove considerable and would necessitate either a large work-force of wire-smiths or perhaps some other, easier, technique of production rather than the use of the hammer or stretching. Indeed, it is apparent from the finds of early Scandinavian/Celtic metal working that the mastery of the art was almost unequalled for the time and it would be surprising to find that ring mail or wire of any description was made solely by the hammer. Finds of 4th century ring mail were found at Thorbjorg and Vimose,¹ while excellent examples of later mail coats (circa 800 AD)² show the advance in the technology of wire, making it doubtful that these coats would be made using a method any different from the "- necklaces of very fine filligree work, or dextrously woven silver wires",³ which have been found and date from the same period, being examples of the same art found in Rhodian and Minoan wire interweave and chain work. Thus, it is probable that wire-drawing was much used in Scandinavia from about the 6th century and perhaps earlier, and though no definite evidence appears to exist⁴ which might support this, there is much evidence for it having appeared as early as the 7th century. A number of authenticated finds of draw-plates dating from early Viking periods have been found.⁵ Of particular note, is the discovery of a plate by Arrhenius, who describes it as a draw-plate originating from Birka, in Sweden, having replacable die inserts. But, because of their softness it is thought that

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- 1 Britannica 13th Ed. op cit Vol. 24 p. 289d.
- 2 Britannica 13th Ed. op cit Vol. 24 p. 290c - The mail shirt or coat was called "byrnie it was often mentioned in Eddic songs. From Beowulf we have: - "The men together: th war-mail coat shone, - Ring-iron sheer (bright ring-mail)" (Thorpe, 1. 645, Zupitza 320
- 3 Britannica 13th Ed. op cit Vol. 24 p. 290c - The uniformity of these wires is remarkable.
- 4 Very little ancient Scandinavian text remains extant today - the earliest appears to be poetic and is dated circa 900 - it is however true, that from the finds of anvils and pincers in grave-ships, the art of metal working was held in high esteem.
- 5 Oddy A. "The Production of Gold Wire in Antiquity" Gold Bulletin Vol. 10 No. 3 1977 p. 82.

such plates were used for drawing precious metals.¹ Lewis,² reports the existence of an 8th century draw-plate from Scandinavia, as have other workers. However, in some cases there is some dispute concerning whether or not the plates were used to make wire or short rods for nails.³

Something which gives additional weight to the argument that draw-plates were used by the gold-smiths are the splendid examples of 7th and 8th century jewellery, known as the "Garrick Street Ring" and the "Ring of Ehlla".⁴ The first is, in part, made of "chevron twisted gold wire" while the other has chevron twisted flat-drawn wire in its construction. What is remarkable about these two items lies in the way the wire - under microscopic examination - displays longitudinal, aligned grooves and crystals. These striations are almost certain indications of the use of a draw-plate, and on a number of items - mail, jewellery etc. dating from 7th or 8th century Scandinavia or Anglo-Saxon England - similar surfaces will be seen upon examination. However, what cannot be certain is whether these items were made entirely with wire-drawing methods. It is true to say that though practiced in these times i.e. from about the 7th or 8th century, wire-drawing was certainly not widespread nor anything like general in its use. Many items were still to be produced by simpler, more traditional techniques - the hammer and the anvil, rolling and stretching, would have been methods more common than those utilising a draw-plate. Draw-plates would be expensive in the quantity of iron used and fairly difficult to make. The long, time consuming wire-making methods were at least

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- 1 It is possible that some wire-drawing dies were made of wood - the expert ship building of the Norsemen employed a boring technique which used red hot iron rods to bore through the ships' planks in order to insert plugs or holding pegs. The hole that resulted from this technique was quite fire-hardened (carbonised and hard), a similar application could produce a short term wire-drawing die which would be especially effective for very ductile metals such as gold and silver. Both the boring by hot rods and the use of fire-hardened draw-plates are methods which, in themselves, may be projected into antiquity. The Benedictine Monk, Theophilus (circa 950 AD), recommended that gold and silver chain work be polished and made more uniform by pulling through tapered holes burnt in oak boards. See Lewis K. B. op cit p. 5.
- 2 Lewis K. B. op cit p. 5.
- 3 Oddy A. op cit p. 82.
- 4 The Garrick Street Ring is to be found in the British Museum, catalogue No. 204. The Ring of Ehlla is in the Ashmolean Museum at Oxford, catalogue 1836-68 p. 9. See Jessup R. Anglo Saxon Jewellery. Faber and Faber 1950 p. 134-135.

dependable and cheap. Excepting for those trades which demanded little in material quantity, for example that of the gold-smith, the wire of iron or copper was a considerable undertaking when one accounts for the need to beat plates or bars of large dimension, slit them into strips, roll the leading edge by hammer and then draw through the draw-plate to form the wire.¹ By comparison, the transition from a bar of red hot metal to a rod and from a rod to wire could, and would, have been forged by hand using at the minimum only a hammer and anvil. Wherever capital was available and large quantities of wire were in demand, the draw-plate would be in use. The armourer in a hill camp or later a castle, might be expected to have cutting and drawing equipment. The jeweller too, on a smaller scale, might be equally equipped since it is likely that such a lucrative trade might furnish sufficient funds for what would probably be an expensive but necessary range of equipment. In general, however, it is arguable that the draw-plate was not to be seen as a common tool in the period between the 4th and 10th centuries.

It is by returning to the manufacture of chain mail, that further indications of the spread in use of wire-drawing (using a draw-plate) as a developing technique can be seen. It could only be inevitable, that in those territorial struggles that continued in Europe, the forced improvement of arms and armour would follow as surely as in any modern war and just as those skilled in metal working for war would be strong, those without the skill would be able to offer little effective resistance. Those marauding Norsemen who, by their skill in metal and ships could wage war at will, may not have expected to encounter

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- 1 The draw-plate is in itself, as previously mentioned, a not undaunting task when its manufacture is considered. The casting of such an implement requires a good furnace, sufficient iron and the expertise necessary to punch through the plate to make the die orifice - this in itself, would be the most difficult of tasks for the early metal worker. Alternatively, the plate is cast with a hole in it - but if fine wire is to be made, this demands accuracy in casting and the grinding or filing of the hole after cooling. In either case, a draw hole for wire, without Augers, drills, successful casting techniques or a knowledge of case hardening iron into steel would demand much of the iron-smith - however, with steely punches - often made in ignorance of why a particular process such as rolling a rod in charcoal made a tough punch* - the draw-plate could be made, the punch producing the orifice in a plate made by hammering red hot cakes of iron. * This process of "cementation" was known from about 1400 BC and appears to be an invention of the "Chalybes" of Asia Minor - see Derry and Williams. A Short History of Technology. p. 121.

superior weapons and armour. Nevertheless, merely observing a mailed warrior might have been the minimum that promoted the spread of ring, and chain mail from Scandinavia. Equally, merchants of doubtful allegiance would sell and buy both information and materials from enemy to enemy; trade links, that have throughout history propagated the way of manufacturing goods, were just as notable in these times. More important though are those methods by which cultural and technological structures are transferred from place to place and more probably it was in this way that the knowledge of manufacturing wire and the complex linking needed in the manufacture of chain mail was propagated.¹ So it was that the use of chain mail, a wire product requiring much skill in its manufacture in later times, was by the 12th century well established in most of Europe and equal to anything that had come out of Scandinavia or Persia. As an armour, which provided the greatest protection coupled with freedom of movement, it adorned those with sufficient wealth to acquire it. However, the average soldier of the 12th century, unless under the banner of a wealthy noble, would carry little. The leather tabard, studded with ring mail or rose studs and small plates was the more common.²

Sadly, the technique for making mail wire - and indeed for most ferrous and wire products of this age, cannot be fully ascertained. Though in the 11th century, the Benedictine Monk, Theophilus, described in a treatise the tools (tongs and draw-plates) for drawing wire, the directions for use are not given. The details for drawing copper as compared to iron are omitted, so an evaluation of the progress in wire-drawing by this time cannot be estimated from this tract.³ A reference dated 1265 AD, names one Robert le Wyrdraer⁴ (Robert the Wiredrawer), but the value of this is questionable since in itself it tells us only that the wire was drawn (and not necessarily by the draw-plate, as in

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- 1 See, for example, the history of the "Le Tene" culture through Switzerland, France and England as an example of cultural transfer inherent in the movement of the Celtic tribes previously described. Much the same occurred here as did that described under the Persian - Scandinavian "Baltic Link".
- 2 Barron O. "Arms and Armour" Encyclopaedia Britannica 13th Ed. op cit Vol. 2 p. 585.
- 3 Hendrie R. Theophilus - Arts of the Middle Ages. John Murray 1847 p. 215. See also Dodwell C. R. De Diversis Artibus. London 1961 Ch. 3 p. 8.
- 4 Wardrobe account Henry III 1/31 extracted from Murray J. A New English Dictionary on Historical Principles. Clarendon Oxford 1888 Vol. 24 (W) p. 189 and also Bardsley C. W. A Dictionary of English and Welsh Surnames. Oxford University Press 1901 p. 820.

ancient times the wire could have been "drawn" out by stretching). Nonetheless, we may be persuaded on the evidence above that wire was hand produced using at the minimum a hammer, and at best a draw-plate and tongs. For this period therefore, it is reasonable to conclude that the making of wire by the draw-plate was finding favour and generally displacing older methods. However, though it may be so that much wire was the product of the draw-plate, so little of the original material remains that the exact degree to which the draw-plate played its role in wire-making is difficult to establish. But, for the intricacies of jewellery, the embellishment of sword hilts and handles with fine wire,¹ the draw-plate would be utilised - since the knowledge of the draw-plate was intact for the period, it may well be that it could only be applied, as in the examples cited above, to the most ductile metals. The drawing of iron wire would require a draw-plate better able to resist wear in the drawing of iron than those used for the more malleable and ductile metals. Unless money and good facilities were available for the production of numbers of draw-plates or some form of draw-die, or alternatively, a process was known by which the draw orifice could be hardened,² large amounts of iron wire - which would be necessary for full coats of mail or other products - could not easily be manufactured. For these reasons, it seems that the use of draw-plates would be the object of substantial capital investment and, as mentioned earlier, the organisation of a whole number of craftsmen, the availability and smelting of ore, the forging of iron, the processing of rod to wire, the link makers, the plate makers etc., all needed to be co-ordinated. This again implies that particular arts could, and would, develop only in those localities where resources (money, material and expertise) were available. Just such a set of circumstances is to be found in the histories of Paris, Coventry, Augsburg and Nurnberg. Early records of organised wire-industries are to be found there. It has been established

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- 1 The old insignia of the German Empire, the sword of St. Maurice (circa 286 AD), was supposedly made with a handle of wood bound with silver wire, though this is not entirely consistent with the story of him being an officer in the "Theben Legion" exterminated at Octodurum. Roman swords were not usually embellished so!
- 2 See footnote p. 200.

that Paris had eight wire-drawing works within the city bounds by 1270. These works appear to have operated under a clearly defined set of Guild regulations, which governed codes of conduct and the regulation of working hours for wire-drawers.¹ Coventry (and probably York) appear to have established wire trades by 1150 and Nurnberg and Augsburg appear probably earlier (approx. 1100 AD).² It is in Nurnberg and Augsburg that the development of wire working (following the Dark ages) takes the lead from the beginning of the 14th century.

THE BEGINNINGS OF THE ORGANISED WIRE INDUSTRY

By the beginning of the 14th century, both the city states of Augsburg and Nurnberg had become sources for the great trade routes which extended from Italy to the Netherlands. Nurnberg, in particular, was of great importance in the 14th century, but it is in Augsburg that the first mention of wire-drawing as a documented technique and trade is found. As long as wire was formed by the hammer and stretching etc., the artisans and craftsmen were called wire-smiths. The records for Augsburg³ and Nurnberg⁴ change in 1351 and 1360 respectively, when the wire-smiths became known as "drahtzicker" or schokenzier" i.e. wire-drawer and wire-miller. It is not known why the change in title was made at this particular time - neither the name of the wire makers, nor the tradition of the town recorders would vary overnight, and it is likely that the change in title for these craftsmen was a result of both years of transition in the organisation and methods of manufacture, and the familiarity of title as far as the town recorder was concerned. Hence though the records change in 1351⁵ and 1360, it is safe to state that wire-drawing was

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- 1 Thompson F. C. "The Early History of Wire" Wire Industry 1935 Vol. 2 p. 159. See also Lewis K. B. "Wire Beginnings" 1936 Vol. 3 p. 7.
- 2 Feldhaus F. M. in his "Beitage Z. Geschichte des Drahtziehens" in the Anzeiger f.d Drahtindustrie (137, 159, 181) 1910 finds the first evidence for the making of iron wire at Nurnberg as early as 1100.
- 3 Von Stettan "Kunstgeschichte der Stadt Augsburg" Vol. 1 p. 223 - after Beckmann op cit Vol. 2 p. 219.
- 4 Von Murr "Journal zur Kunstgeschichte" Vol. 5 p. 78 - after Beckmann op cit Vol. 2 p. 219.
- 5 This, of course, is the date at which the Black Death was at its height - I cannot establish any connection with this however.

earlier¹ in invention or reintroduction. The development of an organised wire industry at this time may be related to the history and development of the trading houses and free trades in Nurnberg, during the period of interest. Free trades became financially dependent on large trading houses who, with capital available, invested in the extraction of ores, the manufacture, marketing and the general organisation of certain trades to the point where monopolies appeared. This could happen in Nurnberg, since the town council approved of the trade receipts which were possible with this organised industry. The craft-guilds in other towns however, defended successfully against what became known as the transfer-system.² Merchants would offer a cash advance to an independent craftsman or alternatively a supply of raw material - however, this was conditional in that all production by the craftsman was to be cleared and sold by, or through, the merchant himself. In this way, one merchant or a combine gained control of the independent craftsman and reduced him to a worker in a cottage industry. This system appears to have operated most successfully in two trades - sheet brass³ and wire-drawing - both trades requiring a high capital investment in foundries and other equipment.⁴ Thus, as the trading houses expanded, the capital available for a high cost industry such as wire-drawing became available and the profits from wire furnished capital for more investment. Consequently, by the 1360's the art of wire-drawing, an advanced capital industry, became established to the exclusion of the inferior techniques that were used where the cost of a good furnace and a hard-wearing draw-plate was prohibitive, thereby

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- 1 From previous description we know that it re-appeared as early as the 10th century.
- 2 Augsburg experienced a bloodless uprising in 1368, when the 17 major guilds in the town consolidated their control. Personal correspondence with Dr. W. Baer, Oberarchivrat, Stradt Archive Augsburg.
- 3 Discovered at Nurnberg by Erasmus Edner. He separated zinc from zinc slag or furnace calamine in the smelting works at Rammeslburg and detected bands of metalli zinc - mixing them into molten copper he made brass. However, the invention of brass alloys was earlier, using the Lapis Calamaris method but was not brass in the sense of mixing definite proportions of zinc and copper to produce a particular alloy such as 70-30 brass, known today as cartridge brass. See Rickard Thomas A. Man and Metals. 2 Vols McGraw-Hill New York 1932 Vol. 1 p. 158. also Article "Nurnberg" Penny Encyclopaedia op cit.
- 4 Hacdecke H. U. Metalworke Weidenfeld Nicholson 1970 p. 76-77.

protracting the art of making wire by the traditional and more laborious methods. Establishing such a disparity, forced a recognition of those workers operating under the protection of the trading houses and resulted in the change of title from wire-smith to wire-drawer. However, as previously stated, this could not happen quickly, and consequently the introduction of wire-drawing may be placed some time before the change in name, in the town records of Nurnberg. Those craftsmen who retained independence from the combines, were declared unfit to be titled "master" and their work was designated inferior.¹ While in certain instances, this would actually be true, it was not the case with every trade. Though these 'inferior' craftsmen were refused facilities within the city walls of Nurnberg, they set up their work around the city in the bushes of gardens² etc., and in some trades eventually achieved a superior quality of workmanship.³

The ability to cast iron, now possible at this time with improved furnaces, enabled the metal workers to produce better draw-plates. Though the technology to draw wire by this method accelerated the production of wire, the old traditional techniques; hammer work, rolling and stretching, were still retained. Yet, while the fame of Augsburg and Nurnberg spread as the centres of the metal working trades, the rest of Europe benefited only from the goods produced. The dissemination of technical knowledge appeared not to be forth-coming. Many trades, for example basin-beating, became "oath-bound"⁴ and a secrecy and mystery began to cover some of the trades in Nurnberg. The technology of Augsburg and Nurnberg therefore appeared as manufacturing islands in Europe - due to both the reluctance of the guilds and merchants of these towns to disclose their trade secrets, and equally the reluctance of outsiders to attempt to discover or accept new

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- 1 Eventually, by about 1500 the exclusion was completed by ensuring that apprentices in the Nurnberg trades were to come only from within the city itself. The craftsmen became a handpicked elite and competition became almost non-existent, resulting in an absolute non-competitive, monopolistic trade area.
- 2 They became known as "Buch-meisters".
- 3 Hacdecke H. U. Metalwerke op cit p. 30.
- 4 Ibid.

methods of manufacture. The crafts and trades in other areas consequently often appeared not to benefit from the processes and techniques which could be available to them.

Perhaps the arguments that apply for all the years preceding the developments in Nurnberg applied during and after the new industry that appeared there, in that the use of the draw-plate was necessary and essential when, and only when, the desired product was large quantities of good quality wire, there was a market for it, and the technology and finance to manufacture draw-plates and equipment was available and warranted such investment. In circumstances other than these, the making of wire continued to be done by simpler methods - some local industries had need of nothing more as long as poor communication and an ignorance of better methods persisted, and no threat of undercutting by cheaper, more abundant supplies of better quality wire appeared. Moreover, we may remind ourselves that certain metals are more conducive to drawing than others - the black-smith would form any wire needed by the hammer since iron would require great power to draw by plate or stretching. Indeed, stretching, hammering and stretching again was the favoured method for wire-working outside those centres such as Augsburg and Nurnberg where the industry was so far advanced. The quality of wire produced by those primitive methods other than drawing by the plate were poor and could be easily displaced by the superior material coming from Augsburg and Nurnberg. The extent to which competition affected those making wire by traditional methods, not superseded by superior technology, is described in some way by the act of Edward III, which lists "Blanche" or white iron wire (tinned) as one commodity whose importation was prohibited. The acts of 1463 and 1484 also list Latten (brass) as well as iron.² It seems that competition against the English (Coventry and Forest of Dean) wire-makers (prior to the

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- 1 A similar act was signed in the reign of Richard III, as in this case, in an attempt to defend home industries. (Hamilton op cit p. 38).
- 2 Rickard T. A. Man and Metals. op cit p. 536. See also - Article "Wire" Penny Encyclopaedia London 1838 p. 476.

time of Elizabeth) - was intense, and centred mainly on the imports from the German wire industries. Coventry had a long history of trades, there were wire-drawers in the town before 1448¹ and wire-making by hand methods - using draw-plate and tongs - was established probably as early as the Nurnberg trades began wire-making (circa 1100). Ancient techniques were for this period still in evidence and could be seen even in the 14th century. Lewis, for example, showed that stretching wire on spools was still in evidence in 1389² (see Plate 11). Stretching strips into wire was, however, a method far from satisfactory and the draw-plate greatly improved the quality and ease with which wire was produced. In 1320, there is reference in the Calendar Letter Book to one Emma (daughter of William) le Wirdrawrie³ while the Coventry Leet Book of 1430 lists John and Thomas Smyth, both of whom are described as "wirtilmaker" or draw-plate makers.⁴ Attempts to improve the efficiency of wire-drawing resulted first in the appearance of a swing in which the wire-drawer sat (see Plate 12) so as to facilitate a less labourious drawing action. Evelyn, writing in 1675, described how early English wire-drawers had learnt from their Nurnberg counterparts, of some 300 years earlier:-

"In this Parish were set up the first Brass-Mills for Casting, Hammering into Plates, Cutting and Drawing it into wire that were in England. First they drew the Wyre by Men sitting harness'd in Certain Swings, taking hold of the Brass Thongs fitted to the Holes, with pincers fastened to a Girdle which went about them; and then with a stretching forth their feet against a Stump, they shot their bodies from it, closing with the plate again; but this was quite left off, and the Effect performed by an Ingenio brought out of Sweden; which I suppose they still continue."⁵

The "Swedish Ingenio" is indicative of some self-acting machine which operated from a water wheel, a device which had made its appearance first in Augsburg, and came to

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- 1 Poole B. Coventry: Its History And Antiquities. London 1870 p. 33.
- 2 Lewis K. B. op cit p. 7.
- 3 Quoted from Murray J. "Dictionary -" op cit p. 189.
- 4 Ibid p. 332.
- 5 Letter from J. Evelyn February 8th 1675-6 affixed to Page 6 Vol. 1 of John Aubrey's The Natural History and Antiquities of Surrey. 5 Vols. London 1719. See also Thompson F. C. op cit p. 161.

England at least as early as 1565, when the English set up wire-works at Tintern. The incorporation of a water wheel demanded in one machine the same kind of swing as described above. Plate 13 shows the form of machine used for coarse drawing of iron and it indicates clearly the state of heavy wire-drawing techniques in the 16th century. Both the water wheel and the draw-plate are now seen to be added to the swinging platform favoured by some wire-drawers. This is clearly a two-fold development in that the more ductile metals would require less power to form them into wire than the drawing of iron. The simple "swing and pull" method would therefore have evolved into a "crank and pull" technique (see Plate 12), since the drawing of iron demanded relatively greater amounts of power to draw it. The water wheel, as a prime-mover, was a necessary addition in the development and evolution of wire-drawing machinery. It is true, however, that the provision of the water wheel need not have been implemented in those cases where copper or 'latten' were being drawn, since these particular materials could be cut and stretched from "battery" (sheets) into slips before being hand drawn by swing and draw-plate. This, of course, would be wire-drawing on a smaller scale than that of processing iron, which demanded much more power to draw it through, and required hammering into convenient rods before it could be drawn.

The illustration in Plate 13^{*} is a convincing example of the ingenuity that was beginning to be shown in water powered machinery during the late 15th and early 16th centuries. The workman - we may call him a wire-smith - has dug a pit so that his swing will be low and will allow him to remain in line with the tongs and rope which pull back and draw the wire (rod) through the draw-plate.¹ The reciprocating motion is achieved by utilising a crank shaft around which is wrapped a thick leather sleeve - no doubt heavily greased - and as the water wheel turns, the crank shaft, which is affixed to the water wheel, describes its circumference and in a cyclic way causes the rope attached

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1 It is worth noting that the draw-plate in Plate 13 has been slid into guides of wood for ease of removal. The guides had a two-fold advantage in that when all eight draw orifices were excessively worn, the plate could be removed to have the orifices reformed to size by use of the hammer and a pritchel and secondly, the draw-plate itself would be withdrawn and replaced by another, having a different range of draw holes.

* From Biringuccio V. Pyrotechnia. Venice 1550.

to the tongs and the wire (rod) gripped by the tongs to first be withdrawn and then released. However, it is the wire-smith that man-handles the tongs and it is he and his swing which, on the return part of the cycle, releases the pressure on the tongs and swinging forward repeats the cycle. The turning of the water wheel once more causes the rope, the swing, the wire-smith and his tongs - and because he has now taken grip on the rod once more, close to the draw-plate - to draw back and pull through another portion of the rod.

A superior machine was known and it is described first by Eobanus Helius Hesus (1488-1540) in the "Urbs Norinberga" of 1532, and also by Conrad Celtes (1459-1508) who writing about 1490, describes with limited detail the story surrounding the invention of the machine. He writes:-

"They say that the art of reducing and drawing rods by the working of wheels was first discovered by a certain Rudolfus, who, as he sought to hide the art as a close secret and acquire great wealth from it, for that reason inspired a passion for probing into the art in the other citizens, as normally happens with profitable developments, especially among auctioneers - and they seduced and bribed his son to set out in a model of some kind the workings of the little wheels inside and the grips (?) which seize hold of the leaf of steel through the narrow aperture, and so reduce it by tenaciously pulling it, and when the father learned of this act, they say that, driven as it were to furious madness, he determined to slay him, but that the son kept himself out of sight and, slipping out of his hands, escaped.¹

It is unfortunate that there appears no supporting evidence² for this account by Celtes and its credibility is provided with only a minimum of correlation from the account by

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- 1 Celtes C. Urbis Norinbergae Descriptio. Hagenaue 1518 fol. Ch. 5 (B.M. C. 78.d.3, 1-3).
- 2 Von Murr (op cit) could find no trace of such a wire-worker in the records in Nurnberg. It is likely that the name is a corruption of the title of one of the Nurnberg trading houses. To construct such a machine in secrecy would require premises, and capital, this would be inconsistent with the means of an ordinary (sic?) wire-worker.

Hessus. With an ornate poetic construction he describes the workings of the machine:-

"For who, observing with how great a mass of wheels it turns the work, with what force it drags apart the iron so that it is made perfect by genius, so that now just one or two men can do what not even a thousand could when the art was not yet discovered - who, seeing such things would fail to admire them, could fail to condemn all those centuries of idleness reaching back in time of men who never came to know such things, the brilliant inventions of the men of our day?

A great wheel, driven by the force of the river, carries the huge cylinder with it, and turning it rolls it round, and the outer part of this is armed with frequent teeth; these strongly driven, seize and carry off the little machines which stand in their way, which would bring to a halt the teeth themselves and the wheel and the water and the cylinder, loaded with its huge mass, if they did not seize them.

Therefore, when the machine which hangs below is seized with this great force, it moves the whole mass above more swiftly, controlling the instruments by which the thin piece of black iron is torn and made thin for various applications, to take on now these convenient shapes, now those, compelled to be obedient to its command, that is, by indomitable force.

For you can see heads of iron imitating serpents, one tearing the iron with his teeth from the bite of the other; this serpent holds the lump, the other pulls at it. Now while they are doing this, they urge themselves on, struggling with one another in frequent assaults, as briskly as if the struggle on either side is for life itself, not iron; and so, as they hold on to the unformed iron with rapid bites, they work it smooth into a round thread, which when recovered from the serpent mouth, comes curving together into a thousand spirals.

What divinity, what memorable stroke of luck disclosed this art? He was no Thracian or Cretan or Italian who shone out with such genius from which to bestow this art for man's benefit; No, he was a German, a man of Noricum."¹

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1 Hesus E. H. *Urbs Norinberga*, 1532. Also to be found in Hermann M. "Lateinische Literaturdenkmäler des XV und XVI Jahrhunderts" Berlin 1896 p. 47 (1165-1197) (B.M.11305.d.21/11).

The extract is presented with all its intricate detail, and we find within the intricacies of its structure a description of the machine and a rather detached reference to its inventor. Clearly, the machinery is water driven and consists not of one machine, but many, all of which are driven by a main water wheel and some form of gearing so as to turn a common axle for all the wire (rod) making machines. The extract provides us with a clear indication that the smaller machines, which were run off the main axle, were in some way self-acting. The reference "they urged themselves on, struggling with one another in frequent assaults, as briskly as if the struggle on either side is for life itself, not iron; and so, as they hold on to the unformed iron with rapid bites they work it smooth into a round thread -" is indicative of some automatic process where the iron is drawn by continuous action of pincers moving forward, gripping the iron near the mouth of the draw-plate, drawing back, releasing the iron and then repeating once more. This is further supported by the reference to "heads of iron imitating serpents, one tearing the iron with his teeth from the bite of the other; this serpent holds the lump, the other pulls at it -". Again, this must surely be alluding to the draw-plate (this serpent holds the lump) and the tongs/pincers which grips the iron and pulls it through (one tearing the iron with his teeth - and - the other pulls it).

It is apparent that the machinery here described was far from simple in construction. Apart from the water wheel, and the reduction gearing to drive the axle, Hesus informs us that there are further mechanical contrivances which he refers to as "little machines" and we may suppose that by some form of gearing, cams or levers a reciprocating motion was imparted into a set of pincers so that they were able to quickly draw out iron rod. It is to be regretted however, that Hesus is sufficiently obscure to leave us doubting as to exactly what was meant to be conveyed in his description of other areas of this clearly fascinating machine. Little is to be gained from considering such statements as "when the machine which hangs below is seized with this great force, it moves the whole mass above more swiftly". Though it must be admitted that in part something might be lost in translating from Hesus's expert Latin, such poetic constructs as above convey little except to inform us that between the main drive axle and the reciprocating pincer

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movement some intermediate mechanism existed.¹

It is of further regret that Hessus is even more vague concerning the inventor of the machine. His statement that the discoverer was a "man of Noricum" tells us only that he came from somewhere in Bavaria or Western Austria - the fact that Nurnberg lies in this province must remain, unfortunately, coincidental.

We may summarise Hessus's and Celtes's descriptions and conclude that the machine described consisted of a set of pincers which by a contrivance of cog wheels advanced the pincers toward the draw-plate, such that as the pincers advanced they opened, fell against the projecting iron rod, closed and clamping down on the rod drew back from the draw-plate. Similar machines were still in use in some parts of France in 1833, when Holland wrote his "Manufactures in Metal"² but throughout its life it suffered the same disadvantages as any technique, manual or automatic, that employed pincers to grip the rod and pull it through. Thus, for a possible 450 years, any rod or wire manufactured in this way suffered indentation on the surface at regular points along its length.³ In addition, the machines, due mainly to their poor construction, tended to operate by a succession of jerks and any wire or rod drawn in this way suffered an unequal surface. There was considerable time lost between each stroke of the pincers and even more to their disadvantage, the pincers would occasionally fail to take hold upon the wire. Thus, the machines manufactured in any era which were based on pincer action, and in this class we include that of Rudolfus, and the machines of Biringuccio (Plate 13) and Holland (Plate 22), provided rod or wire that became notorious for its coarseness. In later years,

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- 1 Some insight into this may, however, be provided by Ray's description of the Tintern ripping machines. Vide supra p. 53.
- 2 Holland J. *Manufactures in Metal* Vol. 2 Ch. 14 p. 333 to be found in Lardner's *Cabinet of Useful Arts*. London 1839.
- 3 Clements W. J. in his "History of Diamond Drawing Dies" (*Wire Industry* September 1965 p. 880) reported that in some parts of Europe, within living memory, drawing tongs were hitched to bullocks which were driven forward and back as a means of successively drawing wire through a plate. He claims also that quite recently a well-known firm of wire manufacturers in England received a query from a customer abroad, asking why the wire which had been supplied to him was free of tong marks. It seems that this particular customer was still in the habit of receiving wire in that part of Europe which was marked by tongs; the absence of the marks aroused suspicions that the wire from England was faulty.

this drawing came to be called "ripping" or "rumpling"¹ and the defective pincer action, even when designed to produce a pull proportional to load (by means of ring controlled pincers, see Plate 37, relegated its use primarily to drawing coarse iron rod or thick pre-finished wire.²

No great departure, in principle, would be noted if we could examine that "special water-driven machine which the Germans undertook to introduce"³ when the Mineral and Battery Works (and by the same promotion) the Mines Royal began operations in England in 1565 and 1568 respectively.⁴ These operations were begun to exploit the mineral sources in England. Unlike Spain, England could not supplement her treasury with the gold and silver from mines in the Americas. Occasionally, a privateer or pirate would return to England after intercepting a Spanish plate ship but the returns were insufficient to have any great effect on either the economy of Spain or England. The government of Elizabeth was continually short of money - some 5 millions was spent on wars during her time and she died owing some £400,000.⁵

Woollen cloth was the one commodity that expected a high return from export and this was one of the industries in which the Queen's officers Cecil, Pembroke and Leicester saw the easing of the countries economic position. The cloth making required "wool cards", a wood block with leather on one side and a handle on the other. Into the leather were impressed many short wire teeth. By running raw wool between the teeth of

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- 1 It is interesting that the root of the English word "rumple" is the middle lower German "rompelen" which means creased and wrinkled. Indeed, the modern German "rumple" meaning (as in the English) lumpy, uneven or rugged, maintains the usage. From this it seems clear that the coarse drawing of wire had its foundation in the German water driven machines described above and lessens any doubt as to where the machine originated. However, it is more a comment on the character and application of the machines. We are left in no doubt as to the quality of rod and wire that might be produced by them. See ref. 2 below.
- 2 Holland J. (op cit p. 332) says of the technique - "it is still to be met in some of those old establishments where expensiveness, or want of convenience, preclude the use of rollers, and where the "rippers", as the workmen were called, care little about modern improvements."
- 3 Hamilton H. op cit. It seems that Hamilton had a confused understanding of exactly what machines the Germans were to introduce. In explaining "battery" - the process of flattening ingots into plates by means of trip hammers - he says that this is the operation the Germans were going to mechanise by water power - "this is the process which the Germans undertook to introduce". This is stated in the footnote to page 3 and yet, the same again is to be found on page 19. In this instance however, it is a reference to wire-making - "this is the process which the Germans undertook to introduce" - in fact the implied distinction did not exist, they introduced both.
- 4 Ibid p. 10-13.
- 5 Aitchison L. op cit p. 394.

two cards the fibres of the wool would be aligned and interlaced.¹ A similar technique was used in "combing" the wool which was an operation designed to remove short fibres and foreign material. The production of wire was an essential home industry to be nurtured if restricted imports of foreign wire were not to handicap and gall the English cloth-makers who would require innumerable wool cards and combs. In short, many card-makers and wire-workers were busy throughout the country and it was expected that the manufacture of home-produced wire of copper, brass and iron would have a marked effect on the economy of the country, in general, and the wealth of the Mineral and Battery Works and the Mines Royal, in particular. It was, however, an individual who figures prominently in the beginning of the Mineral and Battery Works, which eventually achieved a wide spectrum of privileges for the workings of metals in England. This individual was the Assay Master of the Mint, William Humfrey.² Humfrey had intended to set up a brass works at whatever location could supply the proper copper ores. Christopher Schutz, manager of the zinc mining company in St. Annen Berg in Saxony, who as an act of faith "was bound in the sum of £10,000 to communicate his art of working metals"³ was linked to Humfrey in the same way as Daniel Hochstetter⁴ was linked to the managers of the Mines Royal. Both men had been part of those Germans whom Queen Elizabeth had "sent for" and "other foreigners (some Dutch) whose mines are plentiful (and the arts pertaining to them) who might put us into the track of managing ours in finding and digging them and in smelting and refining metals."⁵

In 1561, Hochstetter was empowered to search for, and was "granted the mines of eight counties"⁶ and to this end he began work. Humfrey, however, had to find his own

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- 1 Hamilton H. op cit p. 8 and footnote.
- 2 The letters patent of Elizabeth dated 1565 refers to him as our "faithful and well-beloved subject William Humfrey, Say Master of our Mint within our Tower of London-
- 3 Stringer M. Opera Mineralia Explicata London 1713 p. 34. He was described as "one Christopher Schutz, an Almain born at St. Annen Berg under the obedience of the elector of Saxony; a work man - of great cunning, knowledge and experience as well as finding the calamine stone called in Latin, Lapis Calaminaris - right and proper for the metal called latten and in reducing it to be soft and malleable." See also Rickard op cit p. 538 and Collingwood W. G. "Elizabethan Accounts - 1564-77" Transcription of the books of the German mines in the Archives at Augsburg. Cumberland and Westmorland Antiquarian and Archeological Society tracked series No. VII Kendall 1912.
- 4 Hochstetter came with Ludwig Haug and Hans Louver of the Augsburg firm of Haug and Co.
- 5 Rickard T. A. op cit p. 538.
- 6 Pettus Sir J. Fodinae Regales. London 1670 p. 20. See also Grant dated 1565 - Domestic State Papers Elizabeth 35, 3; Calendar 1547-1580 p. 245.

ores-to begin his operations which though based on an extensive licence, could not conflict with those mines protected under the charters of the Mines Royal. This charter allowed the Mines Royal to operate those mines of the "precious metals" and copper in the counties of Westmorland, Cumberland, Leicester, Cornwall, Devon, Gloucester, Worcester and the principality of Wales. Humfrey and the Mineral and Battery Works could work those areas not covered by the Mines Royal. However, the two conflicted since copper deposits of the better kind had already been ceded to the Mines Royal through the quick and effective detection of deposits by Hochstetter. But this conflict was soon resolved as it became apparent that the Mines Royal could find a good market for their ores with the Mineral and Battery Works. In this way, the two companies complemented each other.

Humfrey and the Mineral and Battery Works had, as an essential part of their privileges, the rights to manufacture wire of any metal. With the availability of good iron ore in the Forest of Dean and coal from the Bristol area, Humfrey and his workers crossed the Wye and set up works in the proximity of Tintern Abbey. Though difficulties were experienced in making brass - Humfrey's original priority - iron wire was produced in July of 1567 and it was not long before some 25 cwt. of wire was being produced each week. Brass wire (for various purposes, but particularly pin making) began to be produced in 1568, and within the same year both the Mines Royal and the Mineral and Battery Works, under the guidance and efforts of Cecil, became incorporated.¹ The resultant joint stock company was significant in the history of the English wire industry, since for the first time wire was being made within an organised metal-working consortium.

As Tintern was beginning production of wire, with the help of Germans who had perfected techniques of wire-drawing at Augsburg and Nurnberg, a new technique had appeared in Nurnberg itself. As early as 1545, Andrew Schultz had brought to the city from Italy a new method of drawing gold and silver wire, a method and type of wire not before produced in Nurnberg, or known in Germany before this time.² Gold fringes made

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1 Hamilton H. op cit p. 14-16.

2 Beckmann J. op cit Vol. 2 p. 228.

of wire from the process were considered of great novelty and value.¹ The drawing of the wire itself, was carried out by means of carefully manufactured draw-plates and spooling drums designed to pass the wire back and forth between successively smaller holes in the draw-plate. Thin slips of gold were pointed at the end which allowed a section to protrude from the draw die. This section was then pulled through by pincers, coiled once around a horizontal spooling drum and drawn through by turning the drum by hand.² After drawing, the wire was run between two flat metal cylinders and the metal would come out as a regular consistent strip of "tinsel" or "flattened" wire. This "flatting" process was itself not entirely new, Beckmann refers to the flatting-mill at Breslau in 1447 and another at Zwickau in 1506. The invention was originally Milanese, being finally a technique whose machinery - two high grade steel rollers and a winding mechanism - was only available from Schuazabruck in Saxony; except when, (after the death of these artists) this was again lost, they could be obtained from Neufchatel.³ The art of "flatting" wire was designed to allow silk or textile threads to be wrapped in gold or silver to produce gorgeous clothing. The threads came from the rollers with a flat surface which could, with little work, be burnished to a high brilliance resulting in clothes which would shimmer with the lustre of polished gold or silver. By carefully combining the two processes, Schultz produced a desirable commodity.

Though the machinery for making this material was both difficult to operate and when Beckmann wrote in 1794 "still in its infancy", the flatting of wire had from the 1540 s, as it had had in Roman times and earlier, the potential as a lucrative industry. Schultz failed to make much of his technique, but others did. Probably in the early 1600 s, the Augsburg mercantile family of Hopfer brought to the city, the Venetians, Gabriel and

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1 Ibid. It seems that large sums were spent in importing hand made versions of it.

2 Vide supra p. 60 - some insight into the source of this technique is provided by Biringuccio in his *Pyrotechnia*. See Chapter 1 p. 57.

3 Beckmann J. op cit Vol. 2 p. 221.

Vincent Marteningi who were superb workmen in the art. From their expertise, an Augsburgian, George Geyer, learnt the technique and by 1698 the patent for flatting wire went to Geyer and some others, notably Joseph Matti and Moriz Zech, and they gained monopoly on the production of the wire. In this way, "flatted" wire became established as a wire product of importance.

This degree of importance was due however, to the introduction into Nurnberg in 1570 of the fine drawing of gold and silver wire by Anthony Fournier.¹ While Schultz had drawn wire sufficient for the flatting-mills and of satisfactory dimensions for clothing, Fournier drew wire fine enough for weaving into cloth directly, apart from wrapping around textile fibres. This was a contribution toward economy - a course drawn wire because of its diameter, consumed a greater quantity of gold or silver if wrapped around a thread and produced thick and unworkable threads. The act of flatting avoided this problem since a greater surface area with a lower profile could be produced when silk etc., was wrapped with "flatted" wire. The cost was greatly reduced even though the flatting process was an additional production cost.² Now, with Fournier's process, which improved on the technology of Schultz, the need for flatting was no longer necessary and the wire could be utilised direct. In 1592, Frederick Hagelsheimer (also called Held)³ moved his manufactory from France to Nurnberg and obtained a patent of manufacture which continued through him and his family until 1622. This monopoly, utilising the Fournier process, was for the production of precious metal wires used in the making of fine cloth and net.⁴ By the 17th century, John Fournier at Fraystattlein, and in Nurnberg and also Frederick Held of the ancient family of Hagelsheimer, had both acquired considerable wealth from the manufacture of "flatted" gold and silver wire.⁵ The source of this wealth however, must be attributed to the work of the early Italian wire-drawers,

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1 Von Murr (after Beckmann) op cit Vol. 5 p. 88.

2 "Bericht von Gold und Silber Dratziehen; von Lejisugo" Lubeck 1744 p. 199 after Beckmann op cit Vol. 2 p. 220.

3 Von Murr (after Beckmann) op cit Vol. 5 p. 88.

4 Beckmann J. op cit Vol. 2 p. 228.

5 Von Murr (after Beckmann) op cit Vol. 5 p. 88.

for as early as 1535, some ten years before Andrew Schultz moved from Italy to Nurnberg, Biringuccio reported that:-

"Wire - can be made in any diameter and length - so long and thin that it is woven into cloth for dresses just like linen and wool, and it is embroidered in the company of silk without distinction."¹

We may conclude then that the wealth acquired by the families of Held and Fournier were founded on processes well established in Italy, but due to poor communication - either contrived or accidental,² remained unknown in Germany until the arrival of Schultz.

In 1565, a distinctive example of the gold-smiths working apparatus was designed and built by Leonhard Daner (1497-1585) a winepress screw manufacturer of Nurnberg, (see Plate 18).

No doubt arising from his expertise and experience in mechanical gearing, and his understanding of mechanical advantage derived through his experience in manufacturing screw threads, Daner constructed an elaborate but supremely functional hand-cranked draw-bench of the type called a "cric". The machine is notable for both its engraving, which covers the majority of gear and bearing housings; and for the fact that it is the first of its type known, and the earliest example still in existence. The machine, which is now placed in the Museum De Cluny in Paris,³ is operated by crankhandles which, through reduction gears, drive on a rack in the direction of cranking by 11.8 mm for every turn of the crank. The radius of the crank is 385 mm and the total pull of the grips for one tooth displacement of the crank gear can be as high as 210 kg with only one kg of effort applied to the crankhandle. This machine incorporated refinements of an advanced nature, one of the most important being in the way the draw-plate was arranged. The machine could draw wire or moulded strip and to provide the latter, an adjustable draw die, consisting of a pair of plates, each forming half the geometry of the shape to be

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1 Biringuccio V. Pyrotechnia Venice 1550 Ch. 8 p. 139.

2 Trade secrets were often jealously guarded.

3 Catalogue de Musee de Cluny a Paris - inventory "banc d'orfevre" - Cl 16880 a.

drawn, was incorporated. Normally, one plate was arranged to lie above the other, but later instead of two forming plates, one mounted above the other, the static bottom plate, which would have simply drawn a smooth face on a strip, was replaced by a roller, thereby drastically reducing the total friction met in the drawing process.¹ This particular refinement is possibly borrowed from the techniques used in the rollers to be found in the flatting mills - indeed it suggests an early basis for the technique of rolling metal into bars from forged rods. This conclusion was suggested in a paper by Fremont in 1908.² Before leaving Daner's machine, it is necessary to mention the way in which the drawing tongs have been fashioned. Here, unlike earlier machines, the grips are short and rugged with compact jaws and short arms which are hauled together by a ring, (see Plate 5). This most functional tool has its utility and design flattered by surface engraving, making it seem ornamental rather than practical.

The machinery which was earlier used in flatting³ was not dissimilar to that which finally became common in the process of rolling. However, 'battery', which provided the same end product, was the more common process and was traditional, having its origin in the manual working of metal by the hammer and anvil. Both processes required the reduction of a cake or ingot of metal into a strip or plate and necessitated hammering or compression while the metal was red hot and malleable. Some flatting was carried out by a small trip hammer and the scaling up of this, by increasing the dimensions of the machine, allowed the reduction of a bar of metal into a thin enough plate to be cut into strips, prior to the act of drawing it into wire. This kind of machine, along with ore-crushers and drawing machinery was imported, after 1566, into England to promote the mining and metal working of the Mines Royal and the Mineral and Battery Works.

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- 1 Fremont C. H. "Le Banc D'Orfevre du Musee de Cluny" Bulletin De La Societe D'Encourag. pour L'Industrie Nationale - January 1929 p. 67-74.
- 2 Fremont C. H. "Le Debut de L'Evolution du Laminoir" communicated to Academie des Sciences de France in April, 1908. Journal of the French Academy of Science Vol. 12 (1908) p. 15.
- 3 Machines for this process were still being made in the 1890's - Bucknall-Smith op cit p. 25.

At first tilt-hammers, for making plate and bar, were hand operated, (see Plate 15). But, by the end of the 16th century, the majority of continental metal works of any note, and also by this time some of the English ones (e.g. Tintern and later in 1606-7 - Whitebrook), operated as industries where most of the processes for wire-making were water powered. The ore-stamping machines, and also the water powered trip-hammers (see Plates 16 & 17) had certainly all been invented by the time full scale operations had begun at Tintern, in 1567, and similar machinery could be seen at the works.

It was said that as early as 1597, some 5,000 workers employed in the wire industry throughout England depended on Tintern wire for the manufacture of a variety of goods.¹ However, the quality of the English latten or brass wire was, at times, suspect; in 1638 it was reported that the English wire was inferior to foreign and of little use in pin-making of the finer sort.² This was, however, not necessarily a reflection on the expertise of the English wire-drawers, but more a comment on the quality of the latten used in the wire. With varying success, Tintern continued operations and its survival may in some way be attributed to its early failure to produce a brass which was workable into wire. In any case, Tintern had no brief, concerning brass wire, and the failure to produce a satisfactory wire from brass was of no great loss. Pettus, commenting on Tintern's adherence to the manufacture of iron wire, said that Tintern's patents covered "- only iron wire for the making of which, we have mills at Tintern in Monmouthshire."³ Pettus also commented briefly on the general process for brass wire:-

"- but if you make kettles of it, and other work then cast the stone into great pots and large pieces purposely for it, which stones are called Brittain or British stones or Lapis Calaminaris (because they come thence) from which they cut afterwards some ingots; and from them draw wyers, and beat out what they please for other uses."⁴

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- 1 Paar H. W. and Tucker D. G. "The Old Wireworks of the Angidy Valley at Tintern" *Jrn. Hist. Metallurgy Society* Vol. 8 part 3 1975.
- 2 Hamilton H. *op cit* p. 52.
- 3 Pettus Sir J. *Fleta Minor*. a translation by Pettus of the work of the German Assay Master General, Lazarus Erkern - Thomas Dawks London 1683.
- 4 *Ibid* p. 286.

Tintern had totally relinquished its interests in any other type of wire except iron by about 1568, when the Mineral and Battery Works took over the lease.¹ It was rare that Tintern produced wire of any gauge likely to be met in the workshops of the gold or silver-smith - nor is it likely that the processes devised by Schultz and Fournier would have been used if indeed they were at all necessary. The smallest gauge available from Tintern appears to have been equal to a diameter of .024 inches (called 7 band) while the largest exceeded .3 of an inch.² The working of iron into wire required a different method of preparation than did copper or brass. Battery would be used to forge a rod rather than a plate or sheet. Whereas copper or brass was commonly slit into strips to be drawn, iron needed to be preformed into a rod at red heat to enable it to be worked into wire. The forming of iron into plates, so as to follow the same process for brass and copper, was arduous and unnecessary. Water power could eliminate many of the difficulties encountered in producing wire from iron. Ripping or rumpling, the first process of drawing forged rod into rough wire, required a great force and this was supplied by utilising the water wheel. The traction necessary to draw thick rod through the draw-plate was impossible, except by incorporating either water power or teams of horses and oxen. Though uncommon, mills using animal power did exist.³ However, the very existence of a technique, such as ripping, allowed the initial processes at the forge to be modified so that a bar could be cast, or forged, with a trip-hammer. In this way, it could go directly to the ripping machine. It was unnecessary to beat out plates of metal directly into thin sheets so that they could be cut into strips (or slips) and reduced to a thickness suitable for manual drawing benches.* This could be achieved better by coarse drawing with the ripping machines, which would successively reduce the rod to the point where it was

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1 Paar H. W. and Tucker D. G. op cit p. 5.

2 Hamilton H. op cit p. 49. A wire merchant called Steer, enticed some workmen from Tintern to begin a wire works at Chilworth, near London. This was done because of the difficulty in setting up machinery, still at this time known to only a few specialists. In order to evade a charge of violating the privilege of the Mineral and Battery Works, they first used horse power as a prime-mover. It proved too expensive and they were forced to introduce the German water wheels.

3 Donald M. B. Elizabethan Monopolies. Oliver and Boyd 1961 p. 101.

* Such a process was, during Tintern's early operations, tried at Dartford. In 1590, Godfrey Box developed a patent of Bovis Bulmer for the cutting of iron sheet to make nails. (Donald op cit p. 103).

suitable, in Tintern's case, for the medium and fine wire swing drawers.¹ In short, even casting could be utilised, the long process of hammering the metal to sheet could be done away with, as too could the cutting of the sheet. In addition, rods rather than wires could be cast and formed by the same methods and because cast or hammered rods could be made longer and processed while still thick, ultimately the drawn wires could be longer. Without water power, and by this time, the now wide spread and well-known ingenuity of Augsburg and Nurnberg mechanics - England could still have had wire made only by hand and swing.² By 1683, Pettus can say "- but how the kettles are beaten and the wyre to be drawn and extended by water, is to be seen at Ilsenberg and many other places.

The relative efficiency of these improved techniques is indicated by the statistics available for Tintern in the latter part of the 17th century. In 1695, Tintern's upper forge produced 61 tons of "osmonde" iron, all of which went for "fine" wire. The lower forge produced some 81 tons of merchant or bar iron.⁴ This total of 142 tons compares with the 60 tons produced in 1597. In 1574, the drawing of 36 stones of fine wire was accounted for at 10d per stone,⁵ while its selling price was 3s 9d per stone.⁶ The larger gauges (e. g. 'Northern' wire) were made for 4½d per stone but sold for 5 shillings. By 1747, fine wire was being made for 5d per stone.⁷

The fact that copper wire-drawing was not, for this time, a technique within the grasp of everyone is demonstrated by the patent of 1636 granted to one George Danby, giving him the right to; "- the sole melting of copper and casting the same into ingots and making it tough to draw into manufactures - the said copper may be drawn at the bar"⁸ and:-

"- taking only eight pence a pound for drawing thereof as now is usually paid, because if an unskillful or a malicious man should have the drawing of it they may spoil the same."

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1 Vide supra Chapter 1 p. 63.

2 Vide infra p. 25.

3 Pettus Sir J. op cit section 7 p. 287.

4 Paar H. W. and Tucker D. G. op cit p. 1.

5 Donald M. B. op cit p. 108.

6 Ibid p. 102.

7 Ibid.

8 British Patent No. 96 op cit. Actually "barre" (the middle English) appears to refer to the draw-plate.

Apart from the insistence that the drawing of copper wire was not an art mastered by everyone, the patent is important in respect of its claim to "making hard iron soft, and copper tough and soft." This is a clear comment on the importance of making available the right kind of metal before any drawing could be carried out. Though we might, from this point in history, presume that the drawing of wire in Danby's time was a complete and familiar technique, it is only by way of such patents as his that an appreciation of the limitations of those methods in use at the time can be had. Danby's patent shows how important the mechanical properties of the metals to be used in drawing really were. Though it is true that Danby would make every effort to colour his patent specification, in terms most favourable to himself, there is no doubt that it conveys a good indication of the problems to be overcome, at this time, in the preparation and processing of metals. Clearly, a hard iron or a soft copper would not do. The iron would quickly damage a draw-plate or be impossible to pull through, a copper which was too soft would choke the draw-plate and break apart. To some extent, these deficiencies could be remedied by either the improvement in the characteristics of the raw material or by improving the wire-drawing techniques and those components of the wire-drawing machines which demanded specific types of raw material. Hard cast iron for draw-plates was a necessity and the casting of plate was a profitable exercise which was seized in 1638 by Sir George Horsey and some others.¹ These men, not unlike certain predecessors (and ultimately those who came later)² improved the quality of metal available to manufacturers, thereby easing the difficulty of converting poor raw material into marketable products. This could however, be a philosophy which presented difficulties. Preparing a raw material suitable for a particular manufacturing technique could lead to a product which had severe disadvantages, due to the need of orienting its manufacture around the specific properties of a raw material. Consequently, iron suitable for drawing into wire might not be

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1 British Patent No. 117, May 1638.

2 See the numerous British Patents - 113, 170, 192, 206, 239, 264 etc. etc., which purported improvements.

suitable as a wire expected to resist loads when in tension, nor one which would be particularly stiff. So it was, that in 1670 Prince Rupert of the Rhine¹ took out patents for converting tools and wire formed of soft iron into steel. The patent also covered the preparation of the metal before it was to be worked:- "- preparing and softening all cast and melted iron so that it may be filed and wrought as forged iron is." But of singular importance is the section in the title of the patent which reads:-

"Converting into steel - tools files and other instruments forged and formed in soft iron - as also all manner of iron wire after it is drawn -".²

Rupert considered this technique so important that to safeguard the methods employed, he applied for security in the form of a patent which gave him authority to:-

"- take and administer an oath to the several workmen, artificers and persons concerned in Patent 161 neither directly nor indirectly to divulge the same."³

It may be inferred from this that if every wire maker or metal worker knew of the process then no benefit would accrue to Prince Rupert, especially if the process was thought to be unique and likely to be very valuable. In the event, however, there was little gain⁴ - the process, an annealing and case-hardening technique used in conjunction with hot charcoal - was doubtless known to the metal workers in Germany and appears to have been communicated to the Prince during his journeys in that land. (Rupert had spent the years 1654-60 in Germany and no-one had been able to trace him).⁵

Although this present description concerns itself with advances in England, the omission of any mention of the state of wire-working in other European countries should in no way imply that the technology of metal working was falling behind. That parallel, if not advanced techniques, were being utilised in other countries, is demonstrated throughout

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1 More completely - Prince Rupert, Count Palatine of the Rhine, Duke of Bavaria.

2 British Patent No. 161, 1670.

3 British Patent No. 162, 1670.

4 The patents - 161 and 162 - are spaced some 6 weeks apart (1.12.1671 to 8.1.1672) and it seems that 162 is much more an after-thought than a premeditated act against rivals.

5 Dictionary of National Biography Vol. XLIX p. 119 also Encyclopaedia Britannica 13th Ed. (1926) Vol. 23 p. 856.

the early history of the English wire industry by the incessant calls for the institution of trade tariffs and sometimes the absolute exclusion of foreign wire from importation. In 1597, foreign wool cards were excluded, and card wire was banned in 1628. Again, in 1638 the import of brass wire from abroad was restricted.¹ These measures had varying degrees of success in stimulating home trade but certain restrictive patents had been issued to people like Danby and others which:-

"- straightly charge and command all and every person and persons what so ever that neither they, nor any of them do or shall at any tyme or tymes hereafter - import or cause to be imported - any ingot of copper upon pain of our high displeasure."²

Such restrictions had the composite effect of causing profiteering (through monopoly) and depressed home industries which utilised products scarce and expensive because of this. The restrictive patents similar to those of Danby's tended to produce a deficient and erratic market for wire, foreign imports continued to flood in under cover of other goods or in open defiance of trade tariffs. Indeed, smuggling in wire of all descriptions became a lucrative business. This, however, was ignored officially. Government statements attempted to devalue foreign wire and approve domestic products:-

"- iron wire is an art long practiced in this realm - English wire is made of the toughest and best Osmond iron, a native commodity of this Kingdom and is much better than that which comes from foreign parts -".³

Similarly, a paper written in 1712 to influence Parliament, indicates a flourishing brass wire industry. It refers to those members of the United Battery and Wire Company who:-

"- after much puzzling and botching with the assistance of foreign workmen, brought the art of making brass wire to such a perfection as to almost totally exclude the importation thereof from Holland and Germany; so that they supply almost the whole nation with English wire to the great detriment of many honest importers."⁴

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- 1 Hamilton H. op cit p. 283 and 284. The 1597 restriction was a reinactment of Richard III's prohibition.
- 2 British Patent No. 96, 1636.
- 3 Proclamation of Charles I, May 7th 1630 - Sloane Collection (B.M. 2483.f.27).
- 4 A Brief Essay on the Copper and Brass Manufacturers of England. London 1712 (B.M. 8245.a.18).

We may wonder how the admission "with the assistance of foreign workmen" was received. This highlights the skill that countries such as Germany, Holland and Sweden had in producing wire and metal articles. This skill, however, had not been wasted on the English, and in the 82 years that separated the two statements, the English wire industry reached the point where it could but do without "the assistance of foreign workmen".

Other English metal working trades had also made their mark. In 1728, Defoe¹ wrote that English brass and copper goods were greatly admired and that they were achieving a high reputation. Produce of many other countries found itself being displaced by English manufactured goods. The foreign industries were quick to react in much the same way as their English counterparts had earlier, and very soon tariff barriers went up on the Continent. One would expect these tariffs to result in much the same situation as had occurred in England, had the past technological deficiencies of the English wire workers been seen in other countries. This was not the case however. English industries based on wire had been (and still were) dependent to some degree on the expertise of foreigners. Many techniques and much expertise still had to come from abroad in the form of wire-masters, millers and those expert in the mining and refining of metals. Their understanding of the raw material and methods (used in extraction and working) supplied the English craftsmen with the material to make high-quality goods and it was, in the main, the plate, pans and pins which were displacing foreign competition much more than the ingots, cast plates and wire, whatever its quality. (It is to be admitted however that even the English craftsmanship was due, in part, to the influx of foreign workmen into England, especially the Flemings and Huguenots, and of some importance, Palatines).² In the past, and indeed at this time, religious intolerance and persecution had

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1 Defoe D. A Plan of the English Commerce. London 1728 p. 290-91.

2 Hamilton H. op cit p. 65 & 108. In 1707, in an attempt to revive the misfortunes of the share holders of the United Societies (the amalgamated Mineral and Battery Works and the Mines Royal)* the confirmation of charter petition to the Crown had as an inducement "there readiness to take care of, and settle the poor Palatine refugees immediately and set them to work". Several thousand Palatines came to England in 1709. *This later included some other companies.

caused the migration in great numbers of dissenters and religious minorities such as these. In places such as the outskirts of Birmingham they exerted their industry and art and in so doing laid a foundation for English craftsmanship. No doubt many trade secrets reached England this way, though even at this time England was itself riddled with religious infractions. A guild member, or an oath-bound workman, would retain no past loyalties after he had been driven from his home-land and it is in this way that jealously guarded manufacturing techniques became common knowledge in the same trades in England. The secrecy surrounding processes were to be seen in the earlier examples of the Nurnberg trades, (as in the case cited above of Prince Rupert); these attitudes were to persist as late as 1900.¹ To what degree this secrecy was affected, or to what effect the dissemination of ideas by either refugees or reward-enticed workmen from foreign parts had on mocking such secrecy, is in some way described by the ineffective trade tariffs which, though in force at this time, could in no way bar the migrant wire workers' knowledge in the same way as it could material imports as in the case of exclusion orders on the importation of wire.

By the 1700 s, the techniques of manufacturing brass wire in England and France were very similar. It is not that one or the other nationality maintained any great secrecy about their techniques at this time, (neither one nor the other could exceed more than a particular level of technology). It was the care with which the wire was made that determined its quality. It was in the excellence of the brass, copper or iron and the artistry with which it could be worked, that the secrets mainly lay. Trades such as tin-plate workers, box makers, Jack chain makers etc., used wire in a whole range of articles; wire found its way into the making of bird cages, windows, hooks and eyes, farthingales, troupes, stomachers, womens' tiers, corn skryns, knitting needles, fishing hooks, bridles, bits, snaffles, girdles, priming wire, mousetraps, buckles, key chains, pins, spurs, dog couples, hog rings, curtain rings and wool cards.² Though two countries might produce similar commodities, if craftsmanship were less in one than the other, the

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1 Brown N. & Turnbull C. op cit p. 46.

2 J.H.C. op cit Vol. 9 (25th July 1689) also Donald M. B. op cit p. 103.

tariffs and import restrictions were ill-designed to stimulate the poorer country - they could not improve quality by attempting to stimulate an expertise that was not there to begin with.

TECHNIQUES AND PROCESSES - SPECIALISATION IN METHODS AND MACHINES

The gradual specialisation that began to occur in wire-drawing from about the 14th century, resulted by the 1700 s in the establishment of conventions and preferences in methods for drawing wires of different metals. In considering the difference in manufacturing copper or brass wire as opposed to iron wire, there is much to be understood concerning both the nature of producing the metal itself and in the techniques and machine available to process it. So far in this study, the development of wire-drawing has been explained in terms which imply a general method for all metals. As has been shown, this is to a great degree justified for the periods prior to the 1650s. The equipment and techniques for drawing brass, copper, gold, silver or iron were generally the same and differed only in the dimensions of machinery and the extraction and preparation of the raw material. By 1700 however, certain differences, in some cases very marked differences, became apparent. New manufacturing concerns began to favour the total control of manufacture. A brass works might process the copper ore, make the brass, form it into plates and proceed with all the stages of production to (for example) pin making.

The techniques used in such an establishment would differ from those making iron or steel wire in many respects although the differences would comply with the necessities of producing a certain commodity. The jeweller, drawing gold wire would scale down the size of his draw bench; the brass wire maker would utilise some of the iron wire makers processes but perhaps at a different stage of manufacture. The iron wire would demand superior draw-plate, often imported, while the jeweller or brass wire manufacturer found a locally made draw-plate adequate for his needs. In short, by 1700 the days when copper, brass or iron wire would be made by the hammer, the "swing and pull" technique or hand drawing were numbered.

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-We are offered some comparison of manufacturing methods, in both different countries and in different metals, from a number of sources. To first concern ourselves with the manufacture of brass wire is to mention a most important industry for this period. The demand for brass wire was at this time large, and many changes toward efficiency and methods of production were perfected by this industry. Indeed, no stagnation took place in those industries making brass wire and we are to see what important contribution to wire making this industry was to make for some 150 years. For the present however, a description of the manufacture of wire at the Dockwra's copper company, in the late 1690's, may be compared with those at a later date and with techniques used for other metals.

This company¹ was founded in 1692 and had its mills on the Mousley River near Esher in Surrey. Like others it had access to mines and smelting works. Copper was processed into brass and of this some 80 tons per annum was produced, a total equal to the combined out-put of all other companies working brass at this time. The Esher factory was set up to produce brass wire for pins but the brass making was carried out on the premises from cake or bar copper. The factory boasted some twenty four draw benches, which produced brass wire selling at about £8.00 per cwt.² The complete process for the manufacture of wire began with the making of brass in small pots, in which a copper smelt formed from copper cakes was mixed with the zinc mineral, Lapis Calaminaris. The pots were removed from the furnace and after clearing the dross from the surface of the liquid brass, the melt was poured between two stones³ in order to cast a plate of some 70 lbs. When cold, the plate was cut into seven or eight slips (by huge manually operated cutters). The slips were then rolled to stretch them and this was carried out

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- 1 Hamilton H. op cit p. 103. The company was formed following the revival of the English metal working industries which began after the passing of the 1689 act permitting anyone to work copper mines. At the insistence of the English Copper Company the Act was consolidated by the declaration that "- notwithstanding that such mines or ore shall be pretended or claimed to be a Royal Mine or Mines Royal - any law, usage or custom to the contrary withstanding."
- 2 Houghton J. A Collection for Improvement of Husbandry and Trade. Vol. 11 No. 256, 257 dated June 25th and July 2nd 1697. Houghton tells us that the company was set up by Peter (sic - William) Dockwra, he was comptroller of the Penny Post Office - "there were five stocks raised for the finding out of copper which were called Dockwra, Hurn etc."
- 3 According to Houghton (op cit No. 258) these stones were imported from St. Maloes (St. Malo) in Brittany and weighed about 1 ton each. See Pettus (vide p. 220) on Brittain or British stones.

with occasional 'nealing' if needed. This kept the sheets soft and malleable which was a pre-requisite for drawing after these sheets were cut into long threads. After much successive drawing, the wire was then cut into lengths of five or six yards and again into lengths of six to eight inches. This wire was batched into coils of a $\frac{1}{4}$ cwt. and for the making of pins required a further two or three drawings to bring it to size. Finally, these pieces were pointed, had their heads formed, whitened¹ and tied into bundles for sale. A "top" workman could handle 24,000 pins per day.²

The Dockwra company appears to have been progressive on many fronts. Apart from patents for moulding iron and other metals, this company was one of the first, (arguably the first) in England, to utilise rolling mills for the production of sheet copper and brass. The rolling mill was to replace the trip hammer in forming conveniently sized sheets for cutting into threads used in the drawing of wire. In fact, the introduction of rolling as a method of producing sheets, was in some ways a return to the early method of flatting which, like the rolling mills, made use of steel rollers to produce the desired effect.³ The use of the rolling mill at the Dockwra factory, at this early period, is indicative of two points. First, the problem of manufacturing regularly dimensioned rolling gear appears to have been solved and was within the capacity of the iron masters and the iron works. Second, the problem of load distribution on the roller axle bearings appears also to have been solved. The erratic behaviour of both had troubled flatting mill since the 15th century, and it was this which had prompted Beckmann, writing in 1793, to say that the management of flatting "rolling cylinders" requires a dexterity "which only a few artists possess" and as previously mentioned (p. 34), he viewed the whole process as being "still in its infancy".⁴ The Dockwra company surely did possess the expertise and enterprise necessary to incorporate rolling gear into their pin-making process. No doubt the expertise of the iron masters in producing polished steel rollers, as well as cast iron and steel needle bearings and bearing housings, contributed greatly.

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1 With tin and Argol (salts of Tartrate).

2 Houghton J. op cit No. 258 and 259, July 9th - 16th 1697.

3 Vide infra p. 34.

4 Beckmann J. op cit Vol. 3 p. 221.

-While extensive rolling mills were erected at Maidenhead on Thames and at the Mitcham Copper Works at around this time, it is by no means a sign that the trip hammer and the process of battery lost favour overnight. It was to continue alongside a growing popularity for rolling processes for some one hundred years or more; to be superseded by the efficiency of rolling which ultimately produced a greater output with extended continuity and an easy conversion to steam power as a prime-mover.

It was the Staffordshire iron masters who appear to have first utilised the water powered rolling and slitting gear for metals. The working of iron, unlike that of brass, required much more force and the manual methods traditionally used, (either the hammer or the levered snips), demanded some method to relieve the iron workers of this arduous task. The introduction of rolling and slitting of ferrous metals may be dated at approximately 1687, for as Plot tells us, the workers in the mills benefited by much:-

"Not to mention again the vast advantage they have from the new invention of slitting mills."¹

The process entire is further described by Plot as follows:-

"They work it into a Bloom, which is a square barr in the middle - Where of those (barrs) they intend to be cut into rodds, are carried to the slitting mills where they first break or cut them cold with the force of one of the Wheels into short lengths; then they are put into a furnace to be heated red-hot to a good height, and then brought singly to the Rollers, by which they are drawn even and to a greater length, after this another Workman takes them whilst hot and puts them through the Cutters which are of divers sizes and may be put on and off according to pleasure: when another lays them straight also when hot, and when cold binds them into faggots and then they are fitting for sale."²

In comparison to iron, the drawing of brass pins from brass was, in the last

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- 1 Plot R. A Natural History of Staffordshire. Oxford 1687 p. 164. See also British Patent No. 254 (Hale 1687) which refers to "- a certaine Engine or Rollers to - Roll or Mill Plates -" Vide supra Ch. 4 p. 113.
- 2 Ibid p. 163. The reference to Rolling precedes that of the Swede, C. Polheim by 48 years.

analysis, a method founded on convenience. Brass was a material which took to drawing much more easily than the iron with its comparatively poor ductility, or indeed, the prohibitively expensive and mechanically impossible steel wire. Though the latter would have been better suited to making pins, and though expensive, could be got; there were however some three or four times the number of processes involved to turn drawn iron wire into steel and then pins, or drawn steel wire (after about 1650) into pins.¹ Iron or steel wire required much more in the size and the power of machinery used in the initial stages of drawing. In the early era of drawing wire, the best iron for drawing had been found to be that made in an Osmund Furnace², which smelted bog iron using wood as fuel. The malleable iron which resulted, was of good quality and even as late as 1864, it was equal to anything associated with the Blast furnace.³ Such was the quality of the material that it lent itself to those methods of working which could be achieved in earlier times, thus, as previously stated, the material was suitable for the processing methods of the time, but when turned into a product was not necessarily the ideal material for that end product. Moxon, writing in 1689 claimed:-

"There is another sort of iron used for 'wyer' which of all sorts is the softest and the toughest. But this sort is not peculiar to any country but is indifferently made where any iron is made though of the worst sort, for it is the first iron that runs from the Stone where it is melting and is only preserved for the making of Wyer."⁴

So much depended on the material as to what might be done with it after being worked Plot describes the rolling of the metal ingots into bars of uniform dimension ready for slitting. Rolled bar could replace forging, as a superior method of forming iron rod, but it could not entirely displace battery. Nor was it to compete in producing sheet as superior as the flatting rollers or sheet rollers which developed from the Saxony plate

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- 1 In Altena in Germany. According to Lewis (op cit p. 52) one Johann Gerdes, experimenting in the drawing of steel wire, threw some out of the window, disgusted with yet another failure. At the same point, "men came to cast their water". A brown "sull" coat formed on the wire and Gerdes, regaining his determination to continue, found on recovering the wire that it drew without great difficulty.
- 2 Swedish in origin - Asleom or Esleon iron - see Penny op cit p. 477. As early as 167 however, Ray (Vide supra p. 52) refers to it as Osborne iron, while Holland (op cit p. 331) also quotes Orsmund iron.
- 3 Percy J. Metallurgy. London 1864 p. 320-325.
- 4 Moxon J. "Meckanick Exercises" to be found in John Houghton's A Discourse of the Necessity for Encouraging 'Mechanick Industry'. London 1689 p. 14.

rolling mills. While the slitting of bars or sheet to prepare the material for drawing could be achieved by the slitting mills, the material for the slitting rollers could also be provided by battery and bar rolling, flat rolling or casting and forging. In general, the use of battery to produce sheet gave way to flat-sheet rolling, while rod and wire utilised bar rolling and sheet rolling in the preliminary stages. A factory of the late 17th century would incorporate the battery method as part of a production process depending on whether it was producing iron, copper or brass rod and wire. This period was still a transitional one with new methods being introduced and older, traditional, methods still having a use or preference as a function of the period when the wire works had first been set up. Plot informs us how the slitting mill was a new invention in about 1670. Not too many years earlier, in 1665, Andrew Yarranton had visited Saxony and returned, after being "very civilly treated" (curiously a contrast to the secrecy and mystery that normally surrounded new processes both before and after this time) with the knowledge of the methods used to work plate and to tin it. He was not very successful in introducing this into England, but in 1690 John Hanbury at Pontipool, began rolling "Black Plates" instead of producing sheet plate by battery.¹ This process, once again, had its origins in flatting and completed the principal methods available for producing a convenient form of metal able to be slit and drawn.

New techniques, however, did not by their appearance immediately displace traditional methods. It is easy to suppose that with the arrival of a superior manufacturing technique, all others will be superseded and abandoned. That this is not the case in wire technology, will become clear when the wire works at Keynsham are considered - here the methods for producing wire did not change dramatically from the late 1760s to 1927, when the mills closed down. Similarly, we have an account from the antiquarian John Ray (1628-1705), of the Tintern wire works which he visited in one of his journeys around Britain in 1662, (the others being during the years 1658 and 1661). Ray visited the Tintern

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1 Yarranton A. England's Improvement. London 1681 part 2 p. 181.

Abbey wire works some time between the 14th and 19th June 1662¹ and described the activities of wire making there in his 'English Words'.² He begins:-

"They take little square bars, made like bars of steel, which they call 'osborn iron', wrought on purpose for this manufacture, and strain, i.e. draw them at a furnace with a hammer moved by water (like those at the iron forges, but lesser) into square rods of about the bigness of one's little finger, or less, and bow them round. When that is done, they put them into a furnace, and neal them with a pretty strong fire for about twelve hours; after they are nealed, they lay them in water for a month or two (the longer the better) then the rippers take them and draw them into wire through two or three holes.

Then they neal them again for six hours or more, and water them the second time about a week; then they are carried to the rippers, who draw them to a two-bond wire, as big as a great pack-thread.

Then again they are nealed the third time, and watered about a week, as before, and delivered to the small wire drawers, whom they call 'overhouse-men'; I suppose only because they work in an upper room."

Presumably, all the preparation for the ripping house was carried out (for this period at least) by trip-hammers. The process was in no way unconventional and the extract above shows how the pig iron was forged in the traditional method to prepare a suitable raw material, both in its geometry and properties, for the ripping machines. In contrast however, is the earlier description by Plot, which conveys a more efficient method able to provide an end product which not only superseded the hammer-forging of bars but was able to deliver lengths of bar which, with some rolling, could even obviate the necessity of coarse drawing with the ripping machines. It is a further comment on the times, when almost three contemporary techniques, brass pin, iron rod and iron wire manufacture, each retained the elements for a complete, efficient and continuous wire-drawing process

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- 1 Dr. Derham "Select Remains, Intineraries and Life" 1760 reprinted in 'Memorials of Ray'. E. Lankester 1846 p. 178. Ray says simply "went to Tintern Abbey and saw the wire mills there."
- 2 Ray J. English Words. H. Bruges for 'Tho' Burrell. Fleet Street 1674. Article headed "The Manner of the Wire Works at Tintern in Monmouthshire".

Ignorance of other industries or a reluctance to break with tradition, were often reasons for the failure of one industry to incorporate the best of another. Tintern, no doubt, suffered from the constraints imposed by loyalties to traditional methods and the lack of progressive ideas and new money (in the face of reasonable profits still to be gained for its products). Profitable production meant that the stimulus for change was less. Up to 1698, the lessees of Tintern had changed 13 times; the method used to make wire though changed little in appearance even up to the 22nd lessee in 1799.¹ At this date, the essential processes which had been described by Ray, in 1662, were still used as they had been in the 1570s. Indeed, the ripping machines described earlier as emanating from the early Nurnberg wire mills, were to be seen little changed at Tintern when Ray visited there. In describing the ripping house, Ray continues:-

"In the Mill where the Rippers work, the Wheel moves several engines like little Barrels, hooped with Iron. The Barrel hath two Hooks on the upper side, upon each whereof hang two Links standing across, and fastened to the two ends of the Tongs, which catch hold of the wire and draw it through the hole. The Axis on which the barrel moves runs not through the center, but is placed toward one side, viz. that on which the hooks are. Underneath is fastened to the barrel a spoke of wood, which they call a swingle, which is drawn back a good way by the Calms or Cogs in the Axis of the Wheel and draws back the barrel which falls to again by its own weight. The tongs hanging on the hooks of the barrel are by the workmen fastened on the Wire and by the force of the Wheel the hooks being drawn back draw Wire through the holes".²

Plate 19 is a reconstruction of the machines used at Tintern and is based on Ray's description. It conveys a fascinating insight into the simplicity of operation of such a machine. It will be noted that it appears that the mechanism requires a workman to be in attendance, so as to man-handle the tongs onto the rod as the barrel is released by the cam on the water wheel axle. This is the only part of the process admitted by Ray, as requiring manual involvement. Since Ray also gives us that the barrel "falls to again by

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1 Paar H. W. & Tucker D. G. op cit Vol. 9 part 1 (1975).

2 Ray J. op cit.

its own weight" we may presume some automatic action in the machine, after this initial 'setting' by the workmen of the tongs on to the rod. The entire process then, appears to consist of the following procedure. The forged rods would be taken from the "wire pool" and any one rod would have an end rounded on an anvil, using perhaps a trip-hammer and furnace heating. Alternatively, this could have been done at the early forging stages. In any event, the end would be either rounded off and/or descaled just before going to the ripping machine. The rod would then be taken after this operation to the ripping house, now in a fit state for drawing. The machines awaiting new rods would probably be disengaged from the water wheel drive by tying back the swingle (or cam follower) away from the axle cam. The rod is turned so that the rounded, conical end can be pushed through the draw-plate orifice. The swingle is released and the workman lifts the tongs, waiting for the cam position to allow the barrel to swing down causing a forward movement on the tongs. As the pincers, on the tongs, come far enough up the draw-bench to bite on a section of protruding rod, they are dropped along-side the edges of the rod and a moment later the cam profile on the axle rises, causing a retraction of the barrel. As the barrel swings back, the arms of the tongs are tightened by the pull - the pincers dig into the rod and draw it through the draw-plate. At the end of its cycle, the axle cam would release the swingle, the barrel would attempt to return and the tongs would loosen. At this point, the weight of the pincers would be sufficient to cause them to slide down the inclined draw-bench toward the draw-plate and at the next return of the axle cam, the whole process would be repeated, progressively drawing through small sections of rod.

Ray tells us that during this operation "they anoint the wire with Train-Oil to make it run the easier" and evidently this provision would have preceded the first pull, after fitting the rod to the draw-plate. As we are informed further that the rod is drawn to wire "through two or three holes" it appears that each draw-plate had at least two holes or successive reduction was carried out on one machine by using two or more draw-plates, each one behind the other with the first imparting the smallest reduction in the cross-sectional area of the rod.

Since Ray offers no great detail concerning the actual mechanical components of the machine, it is difficult to assess exactly how it stands in comparison to what is known of

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similar machines both before and after this time. Though it is true that perhaps even less is known of the machine of Rudolph of Nurnberg, nevertheless some clear expression of continuity in operation is found in the previous description, which indicates that these Tintern ripping machines were automatic. It follows that they differed little from the machines used at Nurnberg in the 14th century. Such a conclusion is in keeping with the history of those machines used by the German wire-millers. Ray's description of these ripping machines is some 95 years after their introduction by the Germans, and with little effort the lineage of the Tintern machines may be traced back to those of Rudolph of Nurnberg. Additional evidence for this is provided by Heath, who tells us that "the small wire-drawers" of Ray were, as late as 1806, using the primitive 'swing and pull' method for drawing wire,¹ a method reminiscent of the primitive technique used in 14th century Nurnberg.

Holland, in describing the self-acting machines still in use in the older French wire mills of the 1830s, provides a comparison between a more advanced machine then in use, and an older type which is comparable with that found in Ray's description. These French machines had, in the first instance, an advanced form of tong which, by an expanding shank (see Figure 24), repeatedly gripped and released the rod in the drawing process. The return cycle was governed by "an elastic pole"² which returned the lever during the dwell period of the cam and brought the 'nippers' back into position. This construction appears to be the last generation of this type of ripping machine and the unusual tong action is a contrast for this kind of self-acting machine. Indeed, Holland admits that in some machines the tongs "are constructed differently and are of a more simple form" being guided in the direction of the drawing-plate and back again by means of a groove set into the inclined plane. This description is particularly interesting, since it is most probably the answer to the technique by which the tongs on many previous ripping machines maintained a fixed path between the draw-plate and its maximum displacement away from it. In all previous examples, from Biringuccio to these examples cited by Holland, the

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1 Vide supra p. 63.

2 Holland J. op cit Ch. 14 p. 333 .

action of proportioning the pull of the tongs and the pressure of the pincers, to the load, is achieved by means of a ring or link on the arms of the tongs themselves, (see Plate 35 and 38). This particular method of tightening the tongs, appears to have been highly successful - as the pull increased, the ring tried to slide back against the angled arms of the tongs/pincers, thereby closing the arms and increasing the grip. In the example of the ripping machine quoted by Holland, we see that the "grips" (tongs/pincers) close initially, and then are drawn back; but in a way that does not seem to be self-regulating. This type of grip, although closed by the action of the expanding shank, is, if isolated from the shank, similar to the ring closed tongs, familiar in the many previous illustrations, and bears also a similarity to manually operated tongs. It is to be accepted that the arrangement of the pincers at the end of the tongs admit to many variations. But, when comparing the two examples above, any appraisal of the two should also include the caliper type of tong to be found in the machines, such as those illustrated in Plates 23 and 24. In essence, the caliper grip¹ is descended from the type used in medium and fine wire-drawing machines of the design known to Daner, Whereas, the ripping tongs are, at this point in their history, constructed with open jaws producing a pincer action at the end, this design is modified in later machines so that the tool is smaller, much more rugged and more efficient; the jaws now being heavy and presenting a larger area to the sides of the rod or wire.² Further, the pull is controlled by a horse-shoe caliper cast with three pivots, two of them link to the grips and the centre one accepts the drawing motion from the machine. It seems that the efficiency of this particular design was known from the time when casting in the iron foundries was sufficiently expert to manufacture such an implement, and this may be placed at approximately the middle of the 16th century. Previous to this, casting or hammer working could only provide tongs or grips of a rough

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- 1 These became known as Jacobite pincers and as late as 1927, were still to be seen in use in the Avon mills, Bristol.
- 2 The faces of the pincers would probably be ridged and roughened with a file to form a serrated surface.

and ready nature as is clearly illustrated in the extracts from Biringuccio's Pyrotechnia. Since Biringuccio's work was completed in 1535 and Daner's machine is dated at 1597, (and by this time incorporates the new type of grip), the two dates serve as a basis for establishing the appearance of an important development in these machines.

It appears that the machine presented by Holland as being the last of its kind (sic), incorporates all the best points to come out of many hundreds of years of experience with machines of its type. Thus the new type of grip, its operation by expanding shank and a critical angle for both the draw-plate and the inclined draw-plane, is clearly a construction designed in an attempt to eliminate the problems that beset this kind of machine throughout its history. However, though it may be conceded that many problems, such as missing its grip due to poor control, had been eliminated, it was doubtless as jerky and cantankerous as the machine described by Ray.

Thus far, this work has described three machines from three eras, all of which provided the first process for working iron rod into wire. These ripping and rumpling machines were becoming obsolescent by the 1690 s, when Plot informs us that rolling rod and plate was becoming a perfected process. For reasons that must include factors such as tradition, a less than meteoric expansion of the rolling mills, and the need to maintain low capital equipment wire mills, the ripping machines were slow to die out. More important however, may be the fact that the ripping of iron rod preceded as a mechanical process the medium wire-drawing machines, which incorporated tongs at first but later grips. These were developed alongside the ripping machines and became a familiar method of drawing the finer gauges of wire. This familiarity no doubt prolonged the useful employment of ripping machines in the iron wire industry, but this adherence to an out-dated technique was never in question in the brass and copper wire industries. Notwithstanding the arguments against it, ripping proved its convenience as a method by surviving as a discrete process for so long. However, the production of rolled rods demonstrated that while ripping was entirely satisfactory for some applications - primarily the first stage reduction of forged rod to wire - it was of little use in producing precision

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rods and shafts for engineering purposes. In 1766, John Purnell obtained patents¹ on a machine employing grooved rollers, designed for making ships' bolts and iron and steel rods and wires, (Plate 40). Again, this particular idea was conceived to answer a specific task and was unique on two counts. The first being that the rollers meshed so that the grooves on the rollers could engage in a precise manner, producing a precise article in terms of its dimensions, and second, that here was an example where the intent of the rolling was to make rod and wire both continuously correct in its dimensions and of a high surface quality. It is self evident that even the comparatively crude rolling and slitting mills of Plot's time produced better 'iron faggots' or rod, but Purnell's process excelled even this and by definition, the ripping machines as well. In Purnell's process, no pincer marks disfigured the rod nor was the wire or rod unnecessarily short. More importantly however, the rod was finished round.

The rolling of iron or steel wire or rod, by Purnell's method, directly introduced into the wire industry a technique which hitherto was seldom used where the making of ferrous rod and wire was the prime industry. The copper and brass industries had long embraced the methods of rolling and slitting for their trade, Indeed, these techniques were fundamental to these industries since this approach best suited the processing of ductile malleable materials such as brass and copper. The slitting mills could easily accept sheet brass, even though its source could be both battery or rolled plate. Slitting itself, was only an extension of the use of shears to cut the battery into slips.

It was against this background of changing technology and market demands, that wire-drawing machinery progressed.

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1 British Patent No. 854 1766. While Plot talked of the Staffordshire rolling and slitting mills, appearing in the 1680s, credit must go to Purnell for the direct application of rolling gear to the manufacture of rod and wire preceding Henry Court.

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TRADITIONAL METHODS IN THE DRAWING AND PROCESSING OF MEDIUM AND FINE GAUGE WIRE

With the advent of grooved rollers for making rod and wire, as in Purnell's machinery of 1766,¹ and then later by similar techniques, the practice of rolling copper, brass and iron rod as a preliminary stage before drawing began to spread throughout the wire working industries. The inspiration for this was clearly before Purnell and his method, and may be attributed to the sequence of processes first used in the early Staffordshire slitting mills. Here was a system of manufacture producing slit bar iron which, after ripping, could provide a raw material suitable for the intermediate and fine wire-drawing benches; it gained favour with manufacturing concerns from the time of Dockwra. Some indication of this is provided by methods similar to that of Purnell's, which subsequently appeared and are discussed in this work. All such methods could be classified as initial processes designed to form refined metals such as copper, brass and iron into suitable states for the drawing-benches where the material was reduced even further into various gauges of wire. Though it has been shown that steel and iron tended to follow a different preparation (forging, slitting and ripping) compared to the copper and brass (which was softer and could be processed from battery plates, "slips" and "threads" no major differences in production methods were practiced when these metals came to be formed into medium and fine gauges of wire. Thus, whatever the preliminary techniques applied to any one metal before its arrival at the drawing-benches, the machinery upon which it was to be drawn into these finer gauges, was invariably the same for all classes of material.

One of the earliest accounts of wire-drawing in all its stages, is provided by Biringuccio² who is quoted above³ as describing a type of ripping machine. His description is valid for techniques up to 1800 and explains the methods for drawing wire of gold, silver

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1 Vide supra Ch. 4 p. 116 and Ch. 1 p. 58.

2 Biringuccio V. Pyrotechnia op cit Ch. 8 p. 139-141.

3 See Ch. 1 p. 26.

copper, brass and iron to very fine gauges. Plate 28 (circa 1550 - compare this with Plate 54 of 1760) to be found on page 140 of the *Pyrotechnia*, is an excellent representation of the type of machinery to be found in the wire-drawers work shop of the 16th century. Biringuccio says of one machine that it is "drawing with a heavy capstan", of the other "drawing - with a windlass" and finally the smaller machine is described as "little drums operated by hand".¹ Biringuccio goes on to describe how the machines are utilised in the drawing of the various metals, but excludes heavy iron in his description since he shows how this is initially formed by the water-driven ripping machine. Only after the operation of ripping is the iron processed in the same way as the other metals, by use of the "horizontal drums" but here "it is necessary to have the iron very greatly thinned and annealed well".² In this respect, Biringuccio warns that annealing is essential for all but the most ductile of metals. In addition, rods formed "under the hammer" ready for drawing are both annealed and greased with new wax to promote passage through the draw-plate.³ Draw-plates even in this period, as indeed from the time of Theophilus, had rows of holes of successive sizes, thereby making progressive reduction on either the capstan or windlass types of machines possible, to the point where self-acting tongs, (and here, interestingly enough, the closing ring is shaped like a stirrup), would damage the thin wire by compressing it flat or indenting it badly. At this point, the coiled wire would be taken to the small draw-bench where it was spooled around the horizontal drums, the end would be filed or beaten into a point and pulled through the largest of the range of draw holes available. By winding the two drums successively one way and then the other, the wire would be reduced to a fine filament, its length progressively increasing as the cross-sectional area became smaller. In the drawing of these finer gauges, we are told again that the annealing of metals for this reduction is essential for ease of "spooling", and that "while you are working it you must always keep it greased with new wax".⁴ This is

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1 Biringuccio V. op cit p. 139-141.

2 Ibid.

3 Ibid.

4 Biringuccio V. op cit p. 140.

reminiscent of Ray's observation in 1662, of the Tintern wire workers "anointing" the wire "with train oil"¹ and indeed this practice of continuous lubrication during drawing, is to be found throughout the history of the wire-drawing industry to the present day. Indeed, the early Iserlohn and Altena wire-drawers, during their period of pre-eminence in wire-drawing, used massive amounts of olive oil.²

The three techniques for successfully drawing wire; annealing, cleaning and coating, are practices developed to alleviate major problems encountered as wire-drawing itself developed. Heat treating wire, to relieve the increasing hardness as the draw-plate work hardened the wire, was first done by burying the wire in an open fire. By 1500, this technique was refined and the wire began to be annealed through the utilisation of Bakers' ovens, and by about 1630 annealing pots had been developed.³ The cleaning of rods was traditionally a manual occupation, the rods being distributed to wire workers' families, the cleaning of the rods being achieved by hand thrashing. The practice of mechanically thrashing the rods came later - frequent applications of sand and water greatly assisted, due to its abrasive action, and doubtless this preceded the water powered tumbling barrel in which the rods were agitated in a water-sand mix.⁴ By 1750, rods were being immersed in weak acids to promote descaling.⁵ The wire pools of Tintern promoted a "sull coat" upon iron rods which was the basis for the practice of leaving forged rods for weeks in the "wire pools" before sending them to the ripping houses. Boiling in tartar solution could be seen by the 1800's and pickling in beer or drawing through "small beer" was common also by this time. Sulphuric acid was used in 1805.⁶

It is probable that the early Tintern wire pools both cleaned and coated rod and wire for easier drawing - by 1850, clean water was found to produce a good "sull coat" - this developed from the use of urine in the Altena district in Germany, where urine was first found to produce a soft brown film on steel rods, this facilitated the drawing of steel into

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1 Ray J. English Words. op cit.

2 Lewis K. B. "Wire Beginnings" Wire Industry February 1936 Vol. 3 No. 25 p. 53

3 Ibid p. 49.

4 Ibid.

5 Ibid.

6 Ibid.

wire by acting as a lubricant¹ - previously the drawing of steel had been found impossible and various methods (such as that of Prince Rupert, see p. 224) had been devised to turn iron wire into steel.

While the most informative account by Biringuccio, in his "Pyrotechnia", is a full exposition of the type of machinery common in the drawing of wire in the 16th century, it is suprising to find that, excepting the application of water power for the drawing of fine wire, there is little indication that any great change took place in the construction of wire-drawing machinery from the 1500s, when the Pyrotechnia was published, up to the beginning of the 19th century. Indeed, in one exceptional case, we may place the phasing out of this type of machinery as late as the beginning of the 20th century. Ray's observation of the Tintern works, some 140 years after Biringuccio wrote, informs us only that as far as medium and fine gauges of wire were concerned "there is another mill where the small wire is drawn which with one wheel moves three axles that run the length of the house on three floors, one above another."² However, we know that even at this time, by way of another account that not even the machinery of Biringuccio was in use, so that the "small wire" was still being produced by the primitive methods of sitting a man in a swing and drawing in the manner as described earlier in Chapter 1. The only concession to progress appears to be the application of water power, in contrast to those times when this technique relied wholly on the strength of human limbs:-

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1 Ibid. See also Ch. 1 p. 50.

2 Ray J. English Words. op cit.

"A large beam was erected across the Building to which were affixed as many seats (in the form of large wood scales) as there were men employed, who were fastened in them by means of a girdle that went round their bodies. The men were placed opposite each other while between them stood a piece of iron filled with holes of different bores for reducing the wire to the various sizes. When the iron to be worked was heated the beam was put in motion by means of a water wheel that moved it with the workmen in their seats regularly backwards and forwards. Who, with a large pair of tongs, passed and repassed the iron through the holes till by force they reduced it to the sizes required. The motion was as regular as the pendulum of a clock and, if any one of the men missed seizing the iron with his tongs, he suffered a considerable shock in the return of the beam."¹

In general, water power was applied only in the production of large rods of iron and as Biringuccio tells us, if well annealed, also copper, gold and silver. The man-handling of drawing machinery was common for some three centuries after Biringuccio's time and remained so only because it was within the realms of one man's effort by way of some mechanical coupling, to draw wire of any one particular material from a certain gauge down to smaller gauges. Above some critical diameter of wire, the lack of mechanical expertise and precision of the time tended to make it impossible to gain the mechanical advantage necessary to convert one man's effort, sufficient for the production of any quantity of wire.

Iron was essentially the domain of the large water powered ripping machines, but all the other metals common for this period, as Biringuccio states, could be processed by a number of machines so far described. The exact provenience of these machines is not to be found at this time, but it does not seem unreasonable to propose that just as the large ripping machines, powered by water, were developed to alleviate a great deal of hammer

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1 Heath C. - Article "The First Settlement of Tintern as a Wire Manufactory" found in Historical and Descriptive Account of Tintern Abbey. Charles Heath 1806 p. 3 (B. M. 290. g. 8).

work, so the intermediate machines for drawing the medium gauges came by way of scaling up the machines found in the manufacture of fine wire. These machines which utilised two horizontal drums or spools,¹ embraced the absolutely basic technique, which is so little removed from the previously described methods of hand drawing very ductile metals such as silver or gold by use of only the draw-plate and tongs. Thus, we may look upon this and the first ripping machines as the first generation and possibly the prototype of all other machines for the period 1500 to 1927. In essence, the type of machine utilising a spool (sometimes called a "twin block") was yet to be scaled up in the same way as the large ripping machines were scaled down. But, it is to be seen in much the same form in the early 1760s, providing as a class a substantial percentage of wire-drawing machinery when compared to others similar to the smaller windlass and capstan machines of Biringuccio (see Plate 27). The latter type of machinery however, was still in favour and contributed greatly to the convenience of the wire-drawer concerned with volume production (see Plate 23). However, just as the ripping machines indented the wire by the action of the pincer jaws (grips), so this deficiency was to be found in whatever scale of machinery made use of pincers, and on this basis the spool to spool machine had great advantage. Indeed, the beginnings of a move to improve this type of machine is implied in the writings of Biringuccio - in the last paragraph of his work he says "- I have seen wire drawn out without a water wheel mechanism. This other way is to use horizontal drums, as I told you has been done with gold - the same can be done for a large wheel for turning it", (and) if one did not have water "by a reel, horse or counter weights etc."² This account is clearly arguing that the force necessary to draw wire is either accomplished by a prime-mover such as water, or by achieving some great mechanical advantage in the mechanism, and it is this that the principle of the capstan or windlass did have. Indeed, one wonders why the capstan of Biringuccio has not been modified simpl

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- 1 It seems highly probable that Biringuccio's description of the fine drawing of gold and silver etc., using this technique, is similar to that used by Andrew Schultz in Nurnber in 1545 and was a technique which he had brought from Italy. See Ch. 1 p. 33.
- 2 Biringuccio V. *Pyrotechnia*. op cit Ch. 8 p. 140.

by eliminating the tongs and winding the wire around the capstan shaft. It can only be concluded that this (advantage) was unwarranted, (in terms of the initial length of rod required in the need to first pull through enough to make one turn around the shaft and anchor it). The tongs were probably essential for gripping the protruding end of the rod which, after thinning, was manually pushed through from the back of the draw-plate during the first operation, before drawing commenced. For convenience, the tongs were retained for successive drawing operations.

Unlike these machines, the principle of incorporating a drum as a horizontal windlass to wind through the draw-plate, thereby eliminating tongs, had indeed appeared in China by this time (see Plate 31). The idea of this form of traction may well have been conceived as early as Hellenistic times but only for gold and silver since Hommel,¹ who first observed this technique in China gives reasons why iron, which required repeated annealings between stages of drawing, was not drawn so - the Chinese having failed to realise this. The drawing of iron wire in China therefore, required machines that could draw work hardened wire. High traction machines such as those shown in Plate 31, may well have been inventions of necessity. Plate 30, shows the final processing of iron wire into steel wire for making compass needles - in the workshop shown, the finer reduction is carried out with a hand held draw die. After this process, which was only for finishing off the wire surface and required little effort, the wire would be cut into small lengths, case hardened and magnetised.

Though the Chinese seem not to have encountered it, the problem of indentation and poor traction, due to the use of tongs, can be shown to be no less an inconvenience experienced throughout succeeding eras in European development. Improvements in techniques that were made can be seen to have, on the one hand overcome a number of disadvantages (some of which are described above), and yet at the same time introduced others. In some instances however, these disadvantages were ignored and succeeded in being perpetuated by their incorporation into comparatively complex wire-drawing machines

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1 Quoted by Needham J. Science and Civilisation in China. Vol. 4 part 2 p. 59. Cambridge University Press 1965.

The prime example of this was in machines, which though designed to be entirely self-acting, could only achieve this by incorporating grips or pincers. A very similar machine is shown in Plate 35, and though less than ornate in its construction, it is little removed in design from the machine of Daner¹ from which it appears to have originated. This is a comment on the satisfactory nature of this class of machine which was a design which departed little from its predecessor, but is dated some 163 years later at 1768. This class of machine achieved the force necessary to draw wire by utilising high mechanical advantage (gearing and an extended crank). It evolved from the same principles as those used in the windlass and capstan machines of Biringuccio. It could not however, evade the use of tongs or grips and in later years its application appears to have reverted to the drawing of thicker rods of gilded and plated metals.² In such a role, where short lengths of rod or wire were the norm, it was possible to utilise the intermediate areas of rod or wire which were not indented by the grips. Gold-plated silver wire, or gold and silver-plated copper wire, could at times serve well in only short sections, where the plate-makers trades flourished.

The large forces necessary to draw wire were, even by the 1830s, still founded in the main, on the best ways to utilise the strength of a man. Some effort was made to utilise water power to its best advantage and examples where this was achieved are notable in the ripping machines previously described. In general, where water power could operate large scale machines, the small types could make use of the same motive source. One of the most satisfactory medium drawing machines to be developed is described by Diderot, in the *Encyclopedie* of 1763. This particular machine is not dissimilar in operation to those familiar machines seen in the ripping houses and it is an example where, as in Holland's description,³ refinement has taken the place of evolution. Plates 25 and 26, show the machine installed and in operation, its construction is displayed much

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1 See Ch. 1 p. 36.

2 *Encyclopaedia Britannica* Vol. 20 p. 481-482 (University of Chicago Press 1957).

3 See Ch. 1 p. 55.

more clearly in Plate 24. In essence, the cams (a) depress the pivoted "swingle" (b) and in doing so draw down the right angle lever (g). This, in turn, applies pull to the pincers (h, 3, Figure 22) which draw through the wire. When the cam disengages, the spring pole which has been strained in the process returns the swingle, the pincers relax their grip and move forward along the line of the wire. This operation was repeated on the next cycle of the cam.

This kind of machine was essentially one intended for the drawing of brass wire (or indeed copper) and was capable of a fairly high volume output. This was especially true if, as in Plate 26, the machines operated in tandem. Such a situation was often however, not to be found after the wire manufacturer sold his wares to the pin manufacturer. As previously indicated,¹ brass was a convenient material for the making of pins. Iron was poor in terms of ductility and not appropriate in pin-making, while steel was both very expensive and very difficult to process. Brass was the pin-makers optimum material; it was comparatively cheap, could be worked well and formed a marketable commodity. The small pin-maker, as opposed to a large manufacturer of brass and pins, drew his wire by using the all too familiar techniques originally described by Biringuccio. In Plate 27, the pin-maker draws the wire from one spool to another, the draw-plate is restrained by two stops and is riddled with various gauges of draw holes. Presumably, the pin-master required these numerous gauges, if only to standardise his pin gauge from various gauges of bought-in brass wire. Shown also, are his apprentices - their duty is to unwind and wash the wire before it is drawn.

It becomes clear, as examples from era to era are put in evidence, that only certain mechanical principles are open to those that draw wire by manual techniques. Indeed, in the last analysis the drawing of wire has one principle, (the forcing of a metal through a die) and this is to be found whatever the sophistication in drawing machinery. For this reason then, it is possible to compare 14th century wire-drawing machinery with many of those still in evidence in the 19th century. In the example quoted above, the pin-maker

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1 See Ch. 1 p. 47.

uses a technique dated at about 1750, but comparable with those of the early years of the 16th century. It is possible to compare machines one against the other, again and again, and though concluding that no difference in the essential principles of operation exist, find that some 300 years may separate the design and construction of them. The machine in Plate 22, is from Holland¹ and is of the type used predominantly in the 1830s, but its construction and mode of operation denies no influence from that of many machines which preceded it for over 300 years. The workmen of this time would take a pre-formed rod of say, iron, brass or copper and point the end with hammer or file. This being done, the rod (or indeed, overgauged wire) would be taken to the lever bench (see Plate 38) and loosely inserted into the draw hole by way of the thinned end. The lever, pivoted and attached to grips via a chain, would be pulled back when the grips had closed on the protruding end of the wire. This process enabled a sufficient length of wire to be first drawn through the plate, so that when both wire and plate were transferred to the drawing machine (see Plate 29) enough was available for coupling to a tie peg on the capstan. The lever, when turned, wound the wire through the draw-plate which was held simply by end stops. The wire-drawer was reported as giving the wire a twist as the wire entered the plate. His claim was that this eased the passage of the wire during the drawing operation in which he pushed round the lever with one hand, while carrying the coil in the other.² However, the practicality of this operation is difficult to see, especially when it is disclosed that the handle (marked C in Plate 29) is contrived to extend or be shortened, by having it housed so that it can slide in and out. Whatever the difficulties, this technique stands as part of the experiments of a wire-drawer and the sliding handle appeared to be a facility which enabled various moments of force to be applied to the drum, so that very fine wire-drawing, which required little effort, could presumably be done while standing, straddling the two ends of the bench with the coil of wire in one hand and the other turning the lever.

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1 Holland J. op cit p. 336.

2 Ibid.

The type of machine in use at any one time and in any one locality, often depended on what kind of prime-mover was available. Clearly, some constraints on the design and construction were inevitable, depending on whether or not the machine was to be manually operated or driven by an external power source. However, many examples are available of manually operated machinery very little removed from that operated by, say, a water wheel. In many cases and in many instances, conversion of a manually operated drawing machine necessitated only the introduction of simple gear assemblies to introduce the external power source.

Of those machines which operated through water power, the outstanding type has been described above as being self-acting and employing grips, commonly found in the French brass wire houses between 1730 and the beginning of the 19th century (see Plate 26). This particular type was fundamentally a scaled down ripping machine of the type devised first by Rudolph of Nurnberg - other types incorporated those principles based on the traction produced by utilising a capstan. Examples abound. Plate 33 is a later development of about 1720 to 1830.¹ The shaft (A) is from the prime-mover, in this example water power but later steam. The bevelled wheel (B) is fixed to the shaft and engages a second wheel to drive the drum (C). The drum is made with two holes on its upper surface - from the shaft, which passes through the middle, there protrudes a cross-bit with two prongs. These prongs fit into the corresponding holes in the drum. So long as the two are turning under the load of drawing through wire, the drum remains engaged to the cross-bit. When the tension is relaxed, at the finish of drawing a length of wire which is wound on the reel (D), the drum slides down the shaft, the prongs disengage and the drum stops revolving. Similar to the manual method, (equivalent to this operation and described under Plate 38), a fresh plate and reel of wire would be taken to the machine and when attached, the drum would be lifted and the cross-bit allowed to re-engage.²

In other machines in this class, power to the revolving drum was applied (or not)

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1 Holland J. op cit p. 338.

2 Ibid p. 339.

by means of a foot lever which lifted the entire assembly - drum, shaft and bevel gear - away from the main drive gear. This was achieved by a simple cross at the top of the lever-upright inset into a cavity beneath the revolving drum. Operation of the foot lever lifted the cross-piece and drum sufficiently for the gear to disengage and motion would cease. Plate 36 represents a typical example of this type of machine. Interestingly, this particular draw bench utilises a "peg" draw-plate and the grips and chain, common to previous examples where the wire must be drawn through the draw-plate a little by manual methods, enabling the draw-plate to be located while providing sufficient free wire to be picked up and anchored at the drum or capstan.¹ A contemporary account explains the making of copper and brass wire using a similar type of machine:-

"In the manufacture of copper and brass wire, for the former, the raw material is purchased from the copper merchants in the form of a partially rolled copper strip of considerable length, of $\frac{3}{8}$ or $\frac{1}{2}$ in. in thickness, which is then rolled down to the thickness suitable to produce the wire, then slit by means of what are called slitting rolls, i.e., by means of a series of steel discs, which operate as revolving cutters. A pair of these slitting rolls are so constructed that the discs of one roll fit into the corresponding spaces of the other. These rolls are set in motion by power, and on the rolled strip being presented to them, it is dragged in, and slit longitudinally into as many "strands" of equal breadth as there are revolving discs or cutters; the "strands" are, of course, square. These are converted into round wire, by being drawn through a succession of draw plates, or holes of various sizes, diminishing in diameter. This is effected as follows:- Attached to a long shaft operated upon by power, are a series of bevelled pinions or wheels. In connection with these, and working horizontally, are a number of cast-iron drums, corresponding to the pinions which are made to revolve by means of corresponding bevelled pinions. The drums alluded to have on their upper surface a small clamp operated upon by a screw.

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1 Cyclopaedia of Useful Arts and Manufactures op cit p. 911.

The "strand" is reduced at the end by filing, so as to enter and pass through the hole of the draw-plate. A pair of pincers, operated upon by power, draw the end of the strip sufficiently through, and in length sufficient to permit of its being attached to the clamp. The end of the "strand" is presented to the clamp, the screw is turned; the "strand" attached; the draw-plate is placed behind the two "snags" or pieces of iron which stand perpendicularly on the draw bench, the strand being placed on a reel. The drum is thrown into "gear", revolves, dragging through the strand, and converting it from a square into a round wire. The operation of drawing hardens the wire, and in the process of reduction it is repeatedly annealed.¹

In later years, machines evolved as composites taking the best points to be found in some of the examples given above. One example utilised the self-acting pincers previously mentioned, and in this case they came to be known as "Jacobites" but were used solely for achieving the initial length of wire needed to locate the draw-plate and anchor the end of the wire to the capstan pulley. On this machine, the bevel drive could be engaged or disengaged at will by means of a hand lever — the same drive shaft which carried the bevel also drove a cam which, acting on a lever, imparted a reciprocating motion into the Jacobites. Some 22 to 24 pulls per minute were possible. This provided more than enough wire drawn through the draw-plate to anchor the wire onto the driving drum i.e. the capstan transmitting the motive force. The initial feed through the draw die was achieved by hand rollers,² which followed a small amount of hammer-work by the wire-drawer. Plate 39 shows the entire machine. On inspection, it is seen to encompass the best from every type, class and development in traditional drawing machines. The machine displays many features characteristic of ripping machines, and the reel to reel motion also is reminiscent of many previous examples. The bevel drive too is not unfamiliar, nor the method of controlling it. In short, the machine retained within its

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1 Timmins S. Birmingham and the Midland Hardware District. op cit p. 317. This may be compared to a description by Perrin (op cit p. 59) given at the end of the 19th century - "For all sizes of wire, the tractive power necessary for drawing the wire through the drawplates is furnished by cylindrical drums called "wire blocks", which vary in diameter from thirty inches to six or eight inches, the size being determined by an approximate relation to the size of the wire which is to be drawn. In all cases these wire blocks revolve horizontally and are driven by vertical shafts through the medium of a simple clutch coupling engaged or disengaged by raising or lowering the block itself, one portion of the coupling being cast as a constituent part of the block. The operation of raising or lowering the block is accomplished by means of a treadle which is under the control of the wire-drawer."

2 Day J. Bristol Brass. op cit p. 161.

construction, a complete history of all previous wire-drawing machines and was a true example of hybrid design in wire-drawing technology. This particular type of machine was still to be seen in the Avon Mills at Keynsham as late as 1927.

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EARLY DRAW PLATE TECHNOLOGY

It is from Biringuccio that we have the first indication that draw-plates have evolved from being more than a simple plate of iron with a hole punched through, a description consistent with plate making of early times.^{*} He informs us that the plates are of steel, some "half palmo" long and incorporating several rows of successively sized holes.¹ This in itself, is notable - now, 1535 at the latest, the draw-plates have developed from hammer forged iron, and it has been recognised that steel resists so much better the wear experienced in drawing iron itself, and is therefore a desirable material for the making of draw-plates. More importantly however, the Pyrotechnia of Biringuccio explains another facet of the wire-drawers understanding of his art. In describing the drawing of fine wire by "spooling" the wire around two drums and winding it through the draw-plate,² the technique is further described as requiring that as the wire is drawn through one hole and is due to be fed through the next smaller, the draw-plate is reversed.³ Excepting that now the wire has been wound off one drum and is around the other, the whole process should consist of no more than changing the direction in which the wire is(now)to be wound. The necessity to reverse the plate is clear indication that the plate is uni-directional in its ability to reduce the wire. From this it can only be concluded that as in modern times, the draw orifice is conical in section — shaped so as to accommodate the wire that much more effectively as the wire is drawn through. By forming a plate with the draw

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1 Biringuccio V. Pyrotechnia. op cit Ch. 8 p. 140.

2 See page 60 .

3 Biringuccio V. op cit Ch. 8 p. 140.

* Hendrie R. in his "Theophilus - Arts of the Middle Ages" op cit p. 215 records the writings of Theophilus (circa 1000 AD) who, under the heading "Of the instruments through which wires are drawn", describes draw-plates as "Two irons, three fingers in breadth, narrow above and below, everywhere thin, and perforated with three or four ranges through which holes wires are drawn."

orifice shaped like the mouth of a funnel and having only the final one third of its thickness at the gauge which is required of the wire, the wire or rod passing through does not meet an abrupt change at the mouth of the plate. Indeed, the tapered draw orifice forms the wire gradually and this is desirable whatever the gauge of the wire to be drawn. Biringuccio's opinion of the essential art of making good draw-plates is that it consists of two things - "one is preparing the draw plates so that their holes are kept round" and also that "they should be of very fine steel".¹ Much the same sentiment is shared by Ray² writing in 1674, but he claims that "the plates wherein the holes are, is on the outside iron, on the inside steel". Unlike Biringuccio, Ray is explicit in describing the nature of the draw orifice - "the holes are bigger on the iron side, because the wire finds more resistance from the steel, and is straightened by degrees." This is a convincing indication that by this time (circa 1662) it is understood that a composite draw-plate consisting of iron and steel, and having a tapered draw hole, experiences the greater wear and stress at the tail of the hole rather than at the mouth, where the first part of the reduction of the rod or wire is less difficult.

Reputations for making good (and bad) draw-plates had long become established in both France and Germany by the end of the 18th century and particular techniques for producing various kinds of plates were known sometimes by their place of origin. Thus Holland³ speaks of "Italian wire drawing plates" which bespoke of an exact procedure for manufacturing this kind of draw-plate. This particular method consisted of forming a piece of iron plate into a tray, it would then be filled with broken pieces of cast iron and heated to, what Holland describes as, "welding heat". The tray would then be hammered until the cast iron pieces were welded to the plate. On completion of this process, with the plate still at just below red heat, the draw holes would be punched through from the

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1 Biringuccio V. op cit Ch. 8 p. 140.

2 Ray J. English Words op cit.

3 Holland J. Manufactures in Metal . Ch. 14 p. 335.

back. Holland's opinion of this process is very low and he does not disguise his contempt for this particular method. He dismisses it by saying:-

"Whatever the Italians might do, it is quite certain that no English wire drawer would be able to compose a plate after this fashion. The notion of uniting pieces of cast iron by welding - is incompatible with the slightest knowledge of the metal - to say nothing of the comparative value - of one made of steel."¹

Whatever Holland's views on this type of draw-plate, he does not seem disposed to criticising a similar process used by one of the leading French manufacturers of the time. The factory of Messrs. Mouchel at L'Aigle in the department of L'Orne, is high in Holland's estimation and he sets aside a substantial part of his work in describing the methods of the Mouchel industries. However, an alternative source² describes how the draw-plates in this company are formed by "arranging several pieces of wrought iron in the form of a box with a lid and filling the cavity with cast steel - the whole is then covered with a luting of clay, heated until the steel begins to melt and is worked with a hammer". The similarity of the above description with that process previously described for making "Italian" plates is striking. It is not however, to be taken as the best in the making of French draw-plates, whose reputation had been in the fore from the time of Houghton, who reported in 1697 that "I am informed that the iron we draw silver and gold thro is made at Lyons."³ So great was the reputation of French plates that Holland and others⁴ comment that in time of war (1793-1815) "- a good French draw-plate has been sold for its weight in silver." This most successful type of draw-plate, which deserved so high a value, was formed from a band of iron two inches wide by one inch thick and a foot in length. It was brought to red heat in charcoal and then hammered on one side which worked the surface into grooves and furrows. A mixture of broken pieces of cast iron, charcoal and white woods called "potin" was then fused together by repeated heating and

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1 Ibid.

2 Penny Encyclopaedia London 1838 Vol. 'W' p. 477.

3 Houghton J. "Collections" op cit No. 258 dated 9th July 1697.

4 Holland J. op cit Ch.14 p.339. See also Doctor Ure. Dictionary of Arts. London 1878 p. 1151 and Penny Encyclopaedia op cit p. 477.

quenching, after which the material was laid on the furrowed surface of the iron plate and wrapped in a cloth which had been impregnated with a clay made into a mixture with the consistency of cream. The whole was then put into the forge to heat. This action, along with gentle hammering, welded the potin to the plate - finally the plate was again forged but drawn out in this instance from one foot in length to two. While the plate was hot, the draw holes were punched through, using repeated heating and successively finer punches which resulted in a conical draw orifice. The final punch however, was never put through, the plate-makers preferring to allow the wire-drawers to open the final hole to the size they desired.¹

This kind of process tended to produce a good plate because some form of fusing and sintering took place with the iron and clay to produce a vitreous/steel amalgamate, which was both hard and tough making a very durable draw-plate. The English, however, preferred to put their faith in steel draw-plates which avoided that empirical knowledge necessary for such techniques as used by the French. English plates were variously described as being "a stout piece of shear-steel, about six inches long and an inch and a half in diameter being somewhat reduced in thickness toward each end, like a cucumber, and flattened on one side"² or, "formed of best cast steel about six inches by one and a half inches with a roundish form, with the exception of one flat face".³ In earlier times, the conical draw holes had been punched out as in the examples above, by successively smaller punches, the largest opening the flat side of the plate since this faced the wire.⁴ However, as early as 1860 dies were "sometimes ground out on both sides by the same brass cone or grinder."⁵ Indeed, at about this time, the practice of critically inclining

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1 Holland J. op cit Ch.14 p.340 -after M. Du Hamel "Arts et Metiers" Vol. XV.

2 Penny Encyclopaedia op cit p. 477.

3 Cyclopaedia of Useful Arts and Manufactures - Editor Charles Tomlinson, Virtue & C 1860 p. 911.

4 See the Patents (No. 91, 12th January 1860 and No. 145, 20th January 1860) of Paul Moore and Paul Moore (the younger) of Paul Moore and Co., at Great Lister Street (and Park Mill) Birmingham. The patents describe a method of "chill casting dies or draw-plates of iron or steel" by utilising conical plugs (accurately machined) as part of the mould when casting a draw-plate. The process allowed 'chill' cast plates to be formed without the arduous task of working upon extremely hard and tough metal. The apertures being preformed or moulded in during casting. Like die casting, this resulted in a smooth die surface after moulding and required little extra work to produce a finished plate. See Plate 48.

the angle of the conical section of the draw-die began since it was understood that critical angles existed for drawing particular kinds of metal at high speeds. Angles between 10° and 30° became the norm, and within these two extremes steel, iron, brass and copper were processed.¹

Unbeknown to the French plate-makers of the Mouchel works, they had stumbled on an almost ideal material for draw-plates. The fusing of clay and iron along with the white wood formed a hard glass-like surface with a supremely tough substrate, forming a composite material with a hardness and toughness not to be equalled until the first experiments with tungsten carbide in the early 20th century. However, the admix used by the Mouchel plate-makers was properly superseded by the patent of 1819 taken out by William Brockedon.²

Brockedon had realised that gems and various other precious stones were harder wearing than any available metal composite of the time. Consequently, he made "or caused to be made by drilling and polishing, in the usual methods employed by lapidaries, cylindrical or conical holes with their extremities rounded off through diamonds, sapphires etc." Brockedon intended the gems to be used as draw-dies in drawing wire of "iron, steel, brass, copper, silver, gold, platina - or any other metallic composition." In the event, Brockedon failed to meet his specification, achieving success only in drawing gold, silver, platinum and "silver and copper gilt wires."³ In this however, his work was outstanding. A frame of fine wire in Faraday's laboratory, still to be seen today at the Royal Institution, testifies to Brockedon's efforts to muster interest in his work. The frame displays twelve platinum and silver wires compared to a human hair. The inscription reads as follows:- "Silver wire drawn by Brockedon - from the finer end wire drawn in platinum", the diameters of the wire range from 1/100th of an inch to 1/4000th of an inch and demonstrate clearly the effectiveness of Brockedon's technique in drawing fine wire. Undeniably, his invention was sound in many respects, but the deficiencies

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1 Cyclopaedia of Useful Arts etc. op cit p. 911.

2 British Patent No. 4395 dated 20th September 1819.

3 Brockedon W. "Remarks upon - a New Mode of Wire-Drawing" (delivered May 11th 1826) Proc. Roy. Inst. 1 (Jan) 1827 p. 462.

were plain. The forming of the orifice in a gem was long and arduous if a precise, smooth die wall was to be made. The difficulty of mounting a gem of irregular geometry in a block or plate had to be overcome, since the die needed to be constrained during drawing. Much more important however, was the cost of acquiring large stones to draw the larger diameters of wire. To draw iron or steel, the diamond, because of its hardness, was ideal. But the diamond did not answer to lapping with diamond¹ powder as other gems did, and since iron and steel were in the main drawn in larger gauges "stones of sufficient magnitude could not be procured at a moderate price."²

Brockedon visited Paris, hoping to generate interest among the French wire manufacturers but they, like the English, realised that it was not a technique to improve economy and quality in drawing ferrous wires. Indeed, though Brockedon admitted that eight years after his patent "pierced gems are now generally used by manufacturers of gold, silver and gilt wire, at Lyons in France and in England,"³ his admission was tinged with irony since in many cases his patent had been violated.⁴

The attraction of his technique was its own undoing so far as patent protection was concerned. Brockedon had hoped to play on the high reputation of the French draw-plate and wire manufacturers, but ultimately it was the small scale wire-drawers of Lyons (working in gold and silver gilt) who realised the advantages and incorporated the technique into their trades.* The making of the dies, as too the wires, became part of a cottage industry, and had he lived Brockedon would have suffered a crueler twist of fate when, in England in 1891, it was reported that "the French still retain a high reputation for the manufacture of these gem-draw-plates."⁵ The lack of progress in England in gem dies was basically for the same reasons that the French industrialists had rejected them.

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1 Ibid p. 463. Brockedon, reporting to members at an evening meeting of the Royal Institution on Friday 11th May 1827, stated that "The diamond failed from the difficulty of polishing the hole."

2 Ibid.

3 Ibid p. 462.

4 Dictionary of National Biography Vol. 6 p. 371.

5 Bucknall-Smith J. A Treatise Upon Wire, Its Manufacture and Uses. John Wiley 1891 Ch. 3 p. 113.

* Brockedon may well have seen the results of using his dies on gilt wire, he said "it never removes the gold from the silver and copper-gilt wires, but imparts to the metal a peculiar brilliancy" (Journal of the Royal Institution January 1827 p. 462).

That it was adapted by a French "petite industrie", was the main reason that in France gem-dies were to be available from experts able to scale up their work when the need arrived. Brockedon's work in England had been treated as something of a scientific curiosity, being called at one time "this fanciful application of precious stones."¹ The adoption of Brockedon's techniques by both the French and English industrialists was long in coming. For years the dies were to be restricted to a cottage industry, the manufacturers remaining true to their reluctance and scepticism concerning the ultimate benefits of these kind of draw dies, declining to invest whatever funds were necessary for the organising of a new industry outside their experience. Ultimately, it was the Lyons die-makers who eventually surpassed Brockedon, by producing a diamond die in the 1870s having at last transposed the technique to diamonds that Brockedon had perfected in rubies and sapphires.²

Brockedon, himself, eventually did realise some benefit from his earlier work in gem dies when in 1843 he patented the treatment "- of plumbago by reducing common black lead to powder and then compressing it in vacuo".³ This process produced lead for pencil purer than any technique hitherto available⁴ and utilised ruby dies where the ruby holes "were formed in gems"⁵ chamfered on the small side where the lead was forced through. This technique was, in essence, Brockedon's final but posthumous triumph. Not only did he realise a substantial monetary benefit, but his method probably preceded all modern extrusion processes for plastic sections, metal wires and rods. Thus, the most modern wire-making process is originally Brockedon's superseding even the the diamond dies of the Lyons gilt-wire makers.*

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1 Holland J. op cit Ch. 14 p. 339.

2 Clements W. J. "History of Diamond Drawing Dies" Wire Industry September 1965 p. 880.

3 Dictionary of National Biography Vol. 6 p. 371.

4 Ibid.

5 Cyclopaedia of Useful Arts and Manufactures op cit p. 912.

6 Ibid.

* This does not however deny the influence of Bramah (Hydraulic Press 1795) and those subsequent workers e.g. Burr, who perfected techniques in extruding metal tubing for domestic purposes, and in the case of electrical cables, insulating sheaths.

Apart from the normal round wire, draw-plates were made to accommodate other shapes for certain specialised trades. In this connection, emphasis is laid on the manufacture of wire used for pinions in watch-making, spectacle frame making and the production of lead frame for windows. Of pinion wire, the plates were in the 1830's (and earlier) composed of a steel block which in the first stage of drawing had the very beginnings of a rayed or ridged outline, becoming more pronounced in successive plates so as to progressively form a rod with a toothed circumference. This rod, when cut across its section, resulted in small cogs for watches and clocks.¹ Draw-plates for spectacle frames were shaped so as to produce a grooved strip to accommodate the edge of a lens, while window lead was formed in a glaziers' vice; a plate shaped the lead into a quadrate while two roughened rollers indented one edge to receive the glass.² "Swage" dies were adjustable dies and formed the patterned or contoured edging on ornamental boxes by being made of two sections, which in making the die adjustable in area, enabled one die to form wider or shallower sections as required.³ Of the examples cited above, only the manufacture of pinion wire appears to have demanded extreme care and very specialised machinery for its production. In this respect, the equipment for drawing pinion wire would consist of a long bench, with a guided rack impelled by a spur-gear which was itself driven by a fly wheel. Motion was imparted into the wheel by a winch handle, the wheel equalised any jerky action in the winch and allowed the rack to move back, and evenly draw through a section of pinion wire. The whole process was devised to eliminate the need to wrap or grip the pinion wire as in alternative methods.⁴

These adjustable dies are seen to have their origins in machines similar to those incorporating adjustable roller draw-plates as in that of Daner (p. 36) whose "cric" of 1565, and the method of adjusting the plate, was to be in evidence, with little departure in principle, in many machines of the same class for some two hundred years. Indeed,

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1 Holland J. op cit p. 349. See also Penny Encyclopaedia op cit p. 476-478.

2 Cyclopaedia of Useful Arts and Manufactures op cit p. 912.

3 Ibid.

4 Penny Encyclopaedia op cit p. 478.

though the names 'Wirtle' and 'Wurdle' were in common use as a synonym for a draw-plate (see Chapter 6 p. 149) from about 1400, the name 'Wordle' came to be used specifically to describe a particular part of the draw-plate. In this context, Murray¹ refers to Knight's Dictionary of Mechanics for 1875 wherein, at this late date, 'Wordle' is defined as "one of the pivoted cams in a draw head, capable of adjustment and regulating the size of the throat through which the wire - is drawn."²

As late as 1927, the word 'Wortle' was used to describe a draw-plate as used in the Avon Mills at Keynsham.³ The word 'Wortle' however corrupted:- Wurdle, Wirtil, Whirtle, Wordle, Writel etc., seems to have been specific to the English wire industry from at least 1430 (see Ch. 1 p.24 et seq) and is identified with the plate making and draw dies from before this time, to well into the 20th century.⁴

Whether the plate be a simple peg-die (see Plate 30) consisting of one draw hole and located in a cavity in the draw bench, or indeed an exotic composite, correctly mounted as in those of the French plates in the early 19th century, at some time or another the die would be subject to wear. In this event, the wire-drawer was generally skilled in reforming the draw-plates by using a hammer and a specialist tool called a pritchel. This device was a sharp pointed punch. The face of the die would be hammered to close up the mouth of the die and then when smaller than the original gauge, the pritchel would re-open the orifice to size.⁵

The necessity to continually check on its gauge and subsequently re-size the draw orifice was best alleviated by correct appraisal of the hardness of the processing wire. Proper annealing, lubrication and speed of drawing all played a major role in extending the life of a draw-plate. Many traditional recipes which placed emphasis on one or more of the above were claimed successful for this period. Depending on the metal, various

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1 Murray D. op cit p. 478.

2 It is interesting that a self-adjusting die designed to draw tapered wire for Cannon was first proposed by Leonardo Da Vinci in 1500. See A. E. Popham's 'The Drawings of Leonardo Da Vinci'. Cape 1946 p. 319.

3 Day J. op cit p. 161.

4 Ibid. See also Perrin's description, Vide supra p. 82

5 Holland J. op cit p. 337.

annealing procedures might be followed. Annealing meant often that coils of work-hardened wire would be confined to a close-furnace at red heat for perhaps days.¹ Unfortunately, this would produce a scale on the surface of the wire and this was removed generally by immersion in a hand-cranked (or water powered) revolving cylinder containing gravel and water.² An alternative technique consisted of immersing the wire in an "acid liquor".³ During drawing, the wire might also pass through "starch water" or stale beer grounds".⁴ This helped to remove scale and protect the draw-plate by producing a lubricating film on the surface of the wire as well as acting as a displacing agent for residue on the wire surface. Wax was used in the same context, before and during the time of Biringuccio,⁵ but grease was equal to it as a lubricant and was favoured in the 18th century.⁶ Holland reported that early in the 19th century, a fortunate accident occurred when some acid pickling liquor had had added to it a number of red hot, convenient-to-hand, brass ingots. The intention was to aid the pickling of some iron wire, by heating the acid liquor with the hot ingots. However, some part of the copper in the brass dissolved in the acid and deposited on the wire. On drawing the wire, it was found that it passed through the plate very easily, clearly indicating that the brass introduced slip between the iron wire surface and the draw-plate.⁷ From a similar kind of beneficial accident, the first drawing of steel wire was achieved; the accidental coating of the wire with what became known as a 'sull coat', a soft ferric oxide, introduced through the action of urine and weathering, allowed the wire to pass through the draw-plate with much less effort than before.⁸ Though undoubtedly, at the time of their discovery, the reasons for such improvements were not understood, the processes facilitated a better drawing of wire and extended the life of the draw-plate. It was adjudged that here was an improvement and empiricism dictated that this, in itself, was sufficient. In this context, we may wonder at

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1 Holland J. op cit p. 337.

2 Cyclopaedia of Useful Arts and Manufactures p. 911.

3 Holland J. op cit p. 337.

4 Penny Encyclopaedia p. 478.

5 Biringuccio V. Pyrotechnia Ch. 8 p. 140.

6 Penny Encyclopaedia p. 478.

7 Holland J. op cit p. 337.

8 Lewis K. B. op cit p. 51. See also Ch. 1 p. 50.

the need to leave coils of wire in the wire-pools at Tintern¹ during the period of its activities. Weeks of immersion left a combination of organic deposition and corrosion on the surface of the wire and ultimately, produced a 'sull coat' similar to that found in the drawing of steel wire. Whilst, primarily, all such processes were designed to either allow or improve drawing, it may be argued that in the last analysis the protection of the draw-plate and the maintenance of its dimensions was of equal concern in the drawing process.

Finally, we may review the position of draw-plate technology at the end of the 19th century, by referring to an extract from Perrin. From this it is noticeable that techniques have changed little from those used in the late 18th century (see Plates 52 and 53):-

"The dies used for drawing heavy wires are generally chilled cast-iron blocks, about three inches wide and six inches long, and from one and a half to two inches thick, pierced with from four to sixteen holes, which are roughly formed in the chill. The hole through such a die is slightly tapering for about three-quarters of an inch on the side from which the drawn wire is delivered; a large conical opening, four or five times the diameter of the wire, being cast in the drawplate on the back side, into which the rod to be drawn enters. This conical opening forms a chamber which is useful in retaining any form of lubricating material that may be used in the wire-drawing operation. The portion of the hole which is only slightly tapering on the face of the drawplate is reamed, by means of a three-cornered tapering reamer, to the size of the wire that it is required to produce. In drawing wire the uniformity of the product, of course, depends upon the accuracy with which the reaming operation is performed, and in any mill where the cast-iron dies, as described, are used, their care and formation is given entirely into the hands of experienced die-reamers, and the labour of the wire-drawer is reduced to that of entering the rod into its proper hole and attending to its efficient lubrication. Such dies are used in reducing the metal from rods about a quarter of an inch in diameter, to wires as small as one-tenth of an inch in diameter, a reduction produced by the passage of the metal through holes of five or six different sizes. For the wires of finer sizes, as well as for very large sizes, it is found that the manufacture of chilled plates is too uncertain and expensive, and, therefore, use is made of steel drawplates, which are bored and reamed by the wire-drawers themselves. These steel plates are either large rectangular blocks pierced with many holes for drawing to sizes not smaller than fifty mils or, for the finest sizes, are in the shape called "wortles", which are semi-cylindrical bars of cast steel having a diameter of from one to two inches, and a length of from six to

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1 Ray J. English Words.

eight inches. In these bar holes are bored, which are similar to those already described for chilled plates, but on account of the comparatively soft character of the metal itself, these "wortles" are given sufficient resisting power to stand the operation of drawing by pounding them on the cylindrical face. This pounding closes the hole together, making it smaller than the wire which is to be drawn. After the "hammering-up" is completed, a smooth steel punch is used to swage out the hole to a size closely approximating that of the wire to be drawn, the final size of the hole being given as before by means of a triangular taper reamer. All of these operations are performed by the wire-drawer, and his skill and efficiency depend mainly upon the accuracy with which this work is done.¹

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1 Perrin F. A. op cit p. 58, 59.

CHAPTER 2

COPPER WIRE: THE EARLY MARKETS AND SUPPLIERS

There seems little doubt that drawn* copper wire was an established, though relatively uncommon commodity as early as 1000 AD. The Benedictine Monk, Theophilus¹, described both the working of gilt copper and the tools used in the drawing of wire.² We may infer therefore, that the drawing of copper wire at this time was a familiar process, the more so since it was a convenient metal to draw, due to its mechanical similarity to the two other important ecclesiastical metals, gold and silver. Indeed, the use of copper, in embellishing items of the altar etc., in Church and Monastery, was consistent with the convenience of working copper. Objects such as Pyxes, monstrances, reliquaries and croziers were often of copper. The metal was easily worked, it was cheaper than solid gold or silver and gilded better than bronze. After working copper into say, a casket, copper wire would then be used to enscroll or decorate an ornament (perhaps as a relief on the surface). This could be done before or after the wire and the box were gilded.³ Such techniques with slight variations are in evidence from the 11th century for items such as ecclesiastical trappings; but these were items specific to the Church. The use of copper and copper wire in the many domestic utensils to be found in the trades of copper-smith and brazier etc., (where copper wire played an important role) provided a more extensive role for copper wire. The value of wire in these early times may be judged from the writings of Etienne Boileau (1200-1269). Boileau records that in his time, Paris had eight wire-drawing establishments⁴ and the organisation of these wire-shops was controlled by a set of explicit Guild regulations. One interesting extract from this code of practice refers to the working times for

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1 See Ch. 1 p. 19 and 72.

2 Hendrie R. "Theophilus - Arts of the Middle Ages" J. Murray 1847 p. 215. Ibid p. 333 " - and when silver or gilt copper, or brass, is well tinned you polish it upon the upper surface."

3 Ibid p. 331 - "This kind of work is - rather useful about the borders - table of altars, in pulpits, in caskets for sacred substances - Work of this kind is also made in copper which is tinned - is cleaned and gilt and polished".

4 Lewis K. B. "Wire Beginnings" Wire Industry 1936 Vol 3 No. 25 p. 7.

* For comment on copper and copper alloys made into wire in antiquity by other methods, see Ch. 1.

the wire-shops, and though permitting wire-drawers of iron to "work nights as much as they please", this was not the case for copper wire. The drawers of copper and brass wire were restricted to day time working, though they might run the casting shop during the night and on holidays.¹ Presumably, the working of copper and brass wire entailed operations which could be tolerated in the day time, but became unbearable at night. Perhaps this points to the level of activity (and thus noise) to be found in a wire-shop at this time. Since the drawing of copper and brass into wire was unlikely to differ greatly from the operations necessary to draw iron, it can be concluded that more shops would work at night on the production of copper wire and it would be this collective activity which would disturb the sleep of those citizens in the vicinity.^{*} At the risk of arguing a syllogism, it might further be concluded that copper and brass wire was thus in greater demand than iron, gold or silver wire.

Though mechanisation in the wire industry was developing as early as the trading houses of Nurnberg and the machines of Rudolph^{**}, the practice of producing locally what wire was needed by any one trade, continued up to the 17th century, and in many instances much later. Just as the monkish metal-worker would form his own wire in keeping with a specific application, so the multitude of trades that incorporated wire into their merchandise generally drew their own or bought wire made locally. Only if the quality of wire available locally was poor or if the cost of imported or transported wire was less (or all that could be had), would a tradesman contemplate purchase of foreign copper wire.² In England this practice was common-place well into the 1680 s. Until this time only a small organised wire industry existed in England and just as the Nurnberg trades had

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1 Thompson F. C. "The Early History of Wire" Wire Industry 1935 Vol. 2 p. 159.

2 This was generally so because the craftsmen would be restricted by the gauge of wire available to them. The difficulty of carrying merchandise across the seas would tend to limit the range of cargoes. A few standard gauges, those with the largest market, would be carried and these were generally a selection of gauges utilised by the makers of copper gilt. See over.

* This argument is given some support in the fact that similar restrictions concerning hours of working applied to English wire-workers in the 15th century. (The Worshipful Company of Tin-Plate Workers Alias Wire-Workers, Berry, London 1926) One may ask if the forging of iron rod (in readiness for drawing) makes any more disturbance than the working of copper into sheets and wire

** Vide infra Ch. 1 p. 27.

flourished on locally produced wire, so some English towns such as York and Coventry survived on the strength of their wire drawers.¹ However, much of the copper that was consumed for wire had to be imported from Sweden and during the 1630 s, the copper exports from that country increased, reaching a maximum of 3,000 tons by 1650.² In 1649, Jacob Momma and Daniel Demetrius opened brass mills at Esher using Swedish rose-copper, the quality and availability of English copper being insufficient to support them.³ Though the English copper industry at this time was of little account, the same was not true of the English trades. Many towns such as Walsall, Coventry and Birmingham either had, or were soon to develop, a thriving industry based on copper and brass. Some trades benefited from new import restrictions as in the case where Crown appointed searchers (of imported copper battery, kettles and manufactured brass) would destroy imports of poor quality. Complaints of fraud by English workers who saw imported goods passed off as their own, resulted in even tighter import controls. As early as 1638 a surveyor and sealer of all imported copper goods had been appointed for a period of 31 years. His duties involved the important one of assessing all incoming copper wire, copper gilt or silvered wire and copper rod.⁴ The fact that materials such as these were an

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- 1 The 1636 patent of George Danby (B.P. No. 96) suggests that the art of producing ductile copper was well worth protecting as a rare and lucrative craft. His claim to "the sole melting of copper - making it tough to draw into manufactures -" enabled him to take "eight pence a pound for drawing thereof -". (See Chapter 1 page 40). It is interesting to note that according to E. E. Hale ('Stories of Invention . London 1892 p. 242) as late as 1792, Eli Whitney was forced to revert to a primitive wire-drawing method in order to provide iron wire for the teeth of his early cotton gin. Wire of any description was a rare commodity in the district of Savannah, U.S.A. Hale records (Ibid) that it was " - an article not at that time to be found in the market of Savannah".
- 2 Jenkins R. "Copper Smelting in England from 1688 - 1750" Engineering April 1944 p. 316.
- 3 Houghton J. A Collection for Improvement of Husbandry and Trade . Vol. 11 No. 257 London July 2nd 1697.
- 4 Hamilton H. The English Brass and Copper Industries to 1800. F. Cass & Co. 1926 (reprinted 1967) p. 302-3.

important import in the early part of the 17th century serves to highlight both the poor condition of the English copper industry, and in some way, the extent of the trades in England able to utilise such materials. A good example of the activity in the English copper trades was given by Robert Plot who visited Walsall in 1686 and recounted the central industries there. From his description, it seems clear that the Walsall trades consumed a good deal of copper. In the form of rod or wire, copper would be utilised in the spindles used for spurs, bridles and stirrups, the rivets and handles for pots and jugs, brewing vats and cauldrons and many other vessels. In addition, Plot notes that the copper-smith made "bosses of all sorts, pendants, starrs and labells, coach nails, studs etc.". Again, rod and wire of copper would find a use in the many types of buckle which Plot says were " - also made promiscuously" at this time.¹ As well as these articles, the traditional industries in copper had evolved to cater for commodities more than basic in nature. Copper wire, gilded or varnished was ideal for the more decorative bird cage or brooch clasp. Indeed, the wire drawers of York could, in 1619, offer copper wire in as diverse a range as bird cages or snout rings for pigs.² A large proportion of the copper wire for gilding was however imported; this being more a comment on the surface quality of the imported wire than the lack of English copper wire-drawers.³ Other craftsmen incorporated copper wire in the most basic of articles. The export of copper wire made into chains was able to consume copper wire on a small but steady scale. Most of the copper wire which went into the manufacture of chain work (which could have links made from thick wire or rod) could be home produced since surface quality was not of great importance. The natives of the African Gold Coast however, were even less discerning, simply placing importance on the metal itself, and whether or not the form it took would

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- 1 Plot R. Natural History of Staffordshire . Oxford 1687 p. 377.
- 2 Schubert J. R. "The Pinners and Wire-Drawers of York, 1296-1762"
Jrn. Iron and Steel Inst. 1950 Vol. 1 p. 3-4.
- 3 Hamilton H. op cit p. 277.

enable it to be used in adornments. Herbert, in 1677¹, remarked of the Gold Coast natives that " - of no small esteem are bracelets, copper chains or manellios". Export of these commodities from England was to continue late into the 19th century.

The instrument makers of Oxford utilised copper rod in a much more refined manner. The description of a hydroscope in Plot's "Natural History of Oxfordshire" refers us to the hands of the instrument which were to be seen "bearing pretty hard on an axel of copper".² We do not know the dimensions of this axle, it may suffice to place it either as thick copper wire or a rod. What is of importance however, is the fact that here we see a specific use for copper in load bearing and this represents one further example of the utility of copper rod and wire which by the 1680 s was a common material. It is remarkable then that for England (at least at this time) no recognisable copper industry existed to supply copper wire-bars for drawing by the home manufacturers and craft industries.

At the end of the reign of Charles I, very little copper mining was carried on in England, the Civil War had disrupted much enterprise in the country and the principal mining concern of Elizabeth's day, the Mines Royal, had practically ceased its activities.³ Of the 100 tons of copper used by the copper-smiths in England at this time, the greater part was imported either as copper ingots, books of beaten copper sheet or indeed small amounts of wire.⁴ In 1684, the Commissioners of the Mint proposed the use of tin for the coining of farthings and half-pences in preference to copper. They believed tin to be a native metal and easily available whereas copper was foreign and required both importation and (in consequence) a disproportionate expense.⁵ It was only after the first Acts of Parliament (preceeding the final Mines

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- 1 Herbert T. Travels Into Diverse Parts of Africa . London 1677 p. 23
See also Moore J. H. A New and Complete Collection of Voyages and Travels . London 1780 (BM 10003.f.2)
- 2 Plot R. Natural History of Oxfordshire . Oxford 1676 p. 235.
- 3 See Ch. 1 p. 32.
- 4 Jenkins R. op cit p. 316, see also Houghton J. op cit No. 255.
- 5 Jenkins R. op cit p. 316.

Royal Act of 1693) in 1688, relinquishing the Crown prerogative on mines bearing precious metals, that the recovery of copper ores began once again.*

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- * The principal Parliamentary debates on the Royal Mines, and efforts to persuade various monarchs to relinquish Royal rights and prerogatives (on those copper mines which invariably gave up precious metals in amounts greater in value than the copper) occurred between 1661 and 1693. (1)
- 1661 A bill was proposed to ascertain exactly which mines are designated Royal. (2) Again in 1661 a bill was presented to Parliament to define Royal Mines. It was read twice, committed, reported, recommitted to Committee and once again laid aside. (3)
- 1688 An Act passed which provided that mining ores of copper, tin ore, lead, though possessing some silver or gold, need not be regarded Royal Mines. (4)
- 1689 (20th August) - repeal of the statute made in the fifth year of Henry IV against the multiplying of gold and silver. (5 - Henry IV - 1403 - 4) (5)
- 1691 A bill was raised "to explain a proviso about them (Royal Mines)" - it was so ordered, but not resumed at this time, the Crown withdrawing from a dispute with Sir Cambery Pryse concerning silver bearing lead mines. (6 i & ii)
- 1692 A new bill was raised "to remove doubts" but this did not acquire Royal assent (7) but a little later in 1693 the proviso was approved and ordered (8) in that an Act was passed which prevented disputes and controversies concerning Royal Mines.
- 1 Pettus Sir J. Fodinae Regales. London 1670 p. 9.
- 2 Journal of the House of Commons - Vol. 8, p. 400.
- 3 J.H.C. - Vol. 8, p. 451, 458, 483.
- 4 Rees W. Industry Before The Industrial Revolution. U.W.P. 1968 p. 370.
- 5 Stringer M. Opera Mineralis Explicata. Gough, London 1713 p. 158 - 161.
- i. Act (Royal Mines) 20th August, 1689 - Anno Regni I - Gulielma and Mariae Regis and Regina.
- 6 (i.) J.H.C. Vol. 10, p. 557, 568, 570, 574, 583, 642, (ii) Hamilton op cit p. 101.
- 7 J.H.C. Vol. 10, p. 743, 759, 772, 779, 784.
- 8 J.H.C. Vol. 11, p. 12.

By 1698, five English smelting firms declared that English copper was equal to Swedish, both in price and quality, and could fully supply the home markets.¹

On the manufacturing scene, much change had taken place even before the drawing up of the Mines Royal Act. The Esher Mills of Monna and Demetrius appear to have been thriving for a time, yet by 1692 William Dockwra (Comptroller of the Penny Post) made shares available for a new company to operate from the same Esher Mills.² His operations too, seemed erratic. Houghton quoted Dockwra shares first on 18th April, 1692 but by 1694 these shares had disappeared from the lists.³ Some evidence exists to suggest that Dockwra was eventually taken over by J. Coggs & Co., as early as 1690⁴ and this company itself, was to amalgamate with the Bristol Brass Company in 1709. At the time of Dockwra however, the Restoration was breathing new life and expectancy into the two "crown companies", the Mines Royal and the Mineral and Battery Works. Both these concerns were consolidated under the authority of Prince Rupert of the Rhine. The consolidation was agreed in 1668 and the new enterprise became known as the United Society.⁵ Little progress was made however, and a less than thriving operation never recovered fully from the Mines Royal Acts of 1688 and 1689 which dissolved their monopoly.

Of the two concerns, the Mineral and Battery Works appears to have played the largest part in supporting the organisation. The Mineral and Battery Works drew much copper wire^{*} and rod, and also produced copper battery as well as copper hoops, thimbles and pans.⁶ At the turn of the century however, operations

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1 Hamilton H. op cit p.106 There appeared to have been five stocks raised "for the finding out of copper" and these are mentioned by Houghton (op cit No. 256) viz - Dockwra, Hern, Derby, Welsh and Cumberland.

2 Houghton J. op cit No. 257.

3 Hamilton H. op cit p. 119.

4 Day J. Bristol Brass. David and Charles, 1973 p. 40.

5 Governors, Assistants, and Societies of the Mines Royal, the Mineral and Battery Works.

6 Stringer M. Opera Mineralia Explicata. Gough. London 1713. p. 221 - 222 et seq.

* According to Sir John Pettus (Fleta Minor . Thomas Dawks - London 1683 p. 131) copper wire was graded and was called 'kafforn dratt'. Acknowledgement to the German wire-drawers brought to England in the 1570's by Elizabeth I. Vide infra Ch. 1 p. 32.

appear to have ceased altogether both in mining and manufacturing. Though a short revival occurred in the period around 1712, by 1740 the United Society was all but finished as a competitive Mercantile concern.¹

The many companies which came into being after the crown prerogative on mines had been revoked testifies to the fact that many recognised the good prospects for copper mining and were prepared to invest in it.² They were encouraged by both "the lately found out art of Calcining the ore with Reverberatory Furnaces and Pit-Coal"³ and the very obvious market available for copper, not only in the form of manufactured goods (utensils etc.) but as copper ingots, sheet, rod and wire. By the beginning of the 18th century, new smelting techniques, rolling and slitting mills and a promising home market had in a few short years accelerated the new English copper industry to the point where Houghton's hope that the industry should be "robust and strong - and fight any should strive to oppose it"⁴ was realised.

Imports of foreign copper goods at this time were mostly Dutch. It was said of it that "most of what's manufactured, comes thence" and they (the Dutch) were admired (by Houghton) as "industrious people".⁵ One example of this industry was that of the instrument maker Muschenbroek "the most famous mechanic of his time"⁶ whose workshop at Leyden utilised copper wire and rod in many of the devices listed in his range of instruments. He was well known for his copper catheters, drilled rods or pipes "to blow up - vessels", "copper nails of different

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1 Hamilton H. op cit p. 63, 66. According to Brown and Turnbull however, ('Century of Copper', p. 14) the Mines Royal were finally dissolved in 1852.

2 Houghton J. op cit No. 255 dated June 18th 1697. "Skillful men think that within 15 miles of London there is a good lead ore, copper and other minerals. Whoever will undertake the work shall have store of share for their work."

3 Houghton J. op cit No. 257 dated July 2nd 1697.

4 Ibid.

5 Houghton J. op cit No. 255 dated June 18th 1697.

6 Erndtel C. H. The Relation of a Journey Into England and Holland in the Years 1706 and 1707 by a Saxon Physician . J. Morphew 1711 p. 61.

sizes" and copper calibrating rods and gauges.¹ Of these Dutch, Houghton relates the expectations of the English copper interests however, by the desiderata "I hope we shall imitate them"², later he echoes the opinion that England would, by 1704, export more copper than Sweden.³

These expectations were founded on a realistic appreciation of the magnitude of copper imports into England and the potential of the English market⁴ as a consumer of copper and copper products. In 1694, 83 tons of copper had been imported from Germany, Sweden, Holland, Spain, Barbary and America. Of manufactured goods the gross weight was probably no more than another three tons, made up of 39 ingots, 12 books of beaten copper, some copper lamps and a little copper-dross.⁵ No copper wire is recorded as an item of import, and in view of the low value of the imports for this time (as compared to the 3,000 tons in 1650), it is plain that the English copper industry was now beginning to make itself felt. Indeed, by 1697 the output exceeded 160 tons - it may well have been more had not the Government placed orders for coinage in 1694 using Swedish copper - as it had in 1672.⁶ Swedish copper was selling for £168 per ton but by 1697 it was reduced to £100 per ton⁷ (in an attempt to undercut English copper). At the same time the Swedes reduced the price of 'Brass' wire from £8 to £5, 5s. per cwt.⁸

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1 Ibid p. 62.

2 Houghton J. op cit No. 255 dated June 18th 1697.

3 Houghton J. op cit No. 256 dated June 25th 1697.

4 Jenkins R. op cit p. 317 - for years the East India Company had been shipping copper to the East. In 1663 copper, gained from Sweden and Germany to the value of £3,500, had been shipped to Bombay.

5 Houghton J. op cit No. 255 dated June 18th 1697.

6 Hamilton H. op cit p. 277.

7 i. Houghton J. op cit No. 256 dated June 25th 1697.
ii. Hamilton H. op cit p. 277.

8 Pettus Sir J. Fodinae Regales. op cit p. 72.

While foreign copper was imported the English smelters felt obliged to concentrate on expanding their markets. Merchants chafed at restrictions on the export of English copper complaining that with both foreign copper being imported¹ and a £5 ad valorem export duty on English copper the home market was too small to support them. However, restrictions were not lifted until 1708 when the export duties on English copper were repealed. At the same time, one Thomas Nisbitt, on behalf of the wire manufacturers, appealed for the remission of the ten pence per cwt duty on the export of English copper and brass wire. He argued that more wire was made than could be sold on the home market, and that free exportation would open markets in Ireland and Russia. As a result of these arguments, an Act was passed freeing wire from duty.²

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- 1 It was said that English copper was not brought to any "great perfection" for some "150 years of working" and that most copper for "the several manufactures of Copper and Brass which we need in great Quantities among us, such as wire, thin Sheet Brass called Black Lattin, Battrey or Brass Kettles, Black-Ware or Mettle - prepared, and the like, have all, till within these few years been brought in from Aboard, to the great expence of Money and Dammage of the trade of this Kingdom." The Case of the Manufacturers, and Workers of Copper and Brass Wire, and Battrey or Brass Kettles etc. in England. (B.M. 8223.e.9.54).
- 2 On the 7th February, 1708 a petition from "sundry Merchants, Braziers and others" was brought before Parliament claiming that "The petitioners have at great charge and industry brought the making of British Copper to that perfection, that they make more than can be expended here and in the Plantations" (Journal House of Commons Vol. 16, p. 95). The House ordered that the duty accounts for the last ten years be brought for examination and these were presented on the 12th February, 1708 (J.H.C. Vol. 16, p. 106). The accounts indicated that duty amounted to £395.13.11½ but showed also that between 1698 and 1706 exports had risen by 600% (Ibid). On 16th February, 1708 Thomas Hisbitt presented his petition stating that £20,000 per annum was paid by England for Brass (Copper) Wire. The petitioners had set up works to "make the same" and now produced more than Great Britain could consume. If "encouraged", he claimed, they could supply Ireland and Russia but only if the duty was relinquished. Charles D'avanant at the Customs House reported that all Brass wire paid the same duty of ten pence per cwt but stated that no separate account was made of "Brass" wire drawn from English Copper upon which duty was laid." (J.H.C. Vol. 16, p. 132). A committee to consider both petitions was appointed on the 5th March, 1708 and both petitions were referred to it (J.H.C. Vol. 16, p. 139). On 8th March, 1708 the duty on the export of English Copper and Brass wire was lifted (J.H.C. Vol. 16, p. 145).

Nisbitt was representing the interests of the few companies then concerned with copper wire, and also those of the Guilds and copper-smiths whose trades also made and utilised wire. But by this time, the growing number of copper mining and smelting concerns depended on the related brass industry and within this industry wire was an important product. Thus Nisbitt acted as representative, not only for the still small wire industry, but also and mainly, for the copper concerns. The remission of the duties on copper and wire displays the growing strength of the English copper lobby at this time. Houghton's wish that the industry would be strong appears not to have been in question. And yet, of the original five companies, mentioned by Houghton, "raised for the finding out of copper"¹ the Welsh and Derby companies were engaged only in mining, and the Herne and Cumberland concerns were smelting companies.² Dockwra appears to have had no interest in copper other than for smelting directly at his brass works (to continue his brass wire operations at Esher) and as an ingredient in the bronze used for the casting of guns in his patent iron moulds.³

In these beginnings in the English copper industry, the copper wire industry has its roots. From a mere six original concerns - and here we include the United Society of the Mines Royal and Mineral and Battery Works - a net-work of mining, smelting, manufacturing and shipping concerns were to arise. In these formative years, copper wire manufacture was not yet a distinct industry, but the concern of those companies who at this time saw copper rod and wire as a commodity convenient in its utilisation of copper. Profitable not only in terms of its easy packing as ships cargo, but also as a small but steady requirement of the individual craftsman.

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1 Houghton J. (op cit) No. 256 dated June 25th 1697.

2 Jenkins R. op cit p. 316.

3 Jenkins R. op cit p. 316.
Hamilton H. op cit p. 103.

CHAPTER 3

THE EXPANSION OF INDUSTRY AND MARKETS

By far the greatest use of copper from the end of the 17th century was to be in the making of latten (brass).^{*} Those companies which were to display the greatest degree of organisation were those of the brass industry which was eventually to centre in the main on the Bristol brass houses. Copper ore and ore refining was essential for the brass manufacturers, but ore distribution was erratic. Some English mining concerns traded by selling their ores in parcels. These would be examined by a prospective purchaser for quality, and if bought, the raw material would then have to be transported by the buyer to wherever it was to be processed.¹ This situation was however, to last only as long as it took for those companies (whose interest lay in the mining, smelting or manufacturing of copper) to organise and expand. Distribution facilities became better as inter-company trading and the market for increased production improved. In 1688, the English Copper Company and the Society of Royal Miners Copper controlled eight copper smelting works, which apart from foreign imports, supplied the whole country.² They were soon to expand, but not in the expected directions. The Cumberland Company (The Society of Royal Miners Copper) operated for but a short time, turning its attention to lead to become merged in the London Lead Company.³ The English Copper Company, however, progressed considerably and when the Dockwra Copper Company was taken over (see page 90) it quickly became the principal supplier of copper amongst the English companies. It began to enlarge soon after 1691 following a petition to Parliament for a grant to manufacture coins of English copper. By 1720, it had absorbed two works at Wimbledon and Redbrook (Glocs);

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- 1 The papers of John Hutchinson (B.M. Add. Ms. 35057 - 170) states:-
"There is no man in England who has a copper mill and ore of his own to make the copper of, but buys the ore in parcels at yee mines as cheap as he can, and he cannot buy it till he sees it because it differs much in its goodness."
- 2 Jenkins R. op cit p. 316.
- 3 Ibid.
- * Variouslly called Lattin or Latten at this time.

the Wimbledon works being a copper mill.¹ Though this company appears to have lost its identity only as late as the end of the 19th century, its chief importance lies in the 18th century, especially from 1720 to 1770.²

Whatever the situation, in terms of the prospects for copper for the first thirty years of the 18th century, the shaping of the English copper industries was always a matter of supply and demand. It was in the interests of the English miners and smelters to eliminate all competition from foreign imports, but they could only do this by being able to meet all such imports not only in terms of price, but also quality. Equally as important was the form the copper took, brass battery, copper sheet, pans, pots, vats, rod or wire, all needed to be manufactured in England for competition to be effective. A typical example of these efforts is seen in the support given by "sundry" copper manufacturers to Abraham Elton, Benjamin Coole, Edward Lloyd and others in a petition to Parliament in March of 1711. The petitioners requested relief from the current import regulations which they claimed favoured the import of foreign manufactured goods of brass and copper.³ The three petitioners principally concerned in the submission represented the Bristol Brass Houses and in particular the Baptist Mills.⁴ It appeared that no great success had been had in the Bristol concern of the Baptist Mills which had experimented in the making of brass since 1702.⁵ The principal objection of the company was that imports of foreign goods were in all respects superior, so that the Brass from the Bristol mills could not compete.

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1 Hamilton H. op cit p. 103 and 148.

2 Hamilton H. op cit p. 245.

3 J.H.C. Vol. 17, p. 118.

4 These mills had formed the nucleus of the Bristol Brass Wire Company when Abraham Darby had gone over from making malt (in 1700) to the manufacture of brass. Darby was joined by Lloyd and Coole in 1702, and by 1709 had removed to Coalbrookdale. (Hamilton op cit p. 109). Whatever this company's successes in Parliament, and it does not appear to have been great, as a manufacturing concern it went from strength to strength. By 1720, it has absorbed the firm of J. Coggs & Co., which appears to have had the Esher mills of the old Dockwra Company (Day J. op cit p. 40), and apart from the new Bristol Mills, it had control of the Warmley Brass Company by the 1770 s. (Day J. p. 92-3). One of the company's earlier acquisitions, the Avon mills at Keynsham, operated from 1707 to 1927 with only one major change in the controlling company (in 1787) throughout this period. (Day J. p. 65-67 and p. 110).

5 House of Commons Committee Reports Vol. 10, p. 666.

But this fact remained mute in the petition.¹ In any case, six days after the petition of Elton, Coole and Lloyd etc., had been laid before the House, a petition of "several merchants and braziers on behalf of selves and many others" requested that they be heard against the raising of import duties on "Battery, Black Lattin, Wire and Metal prepared".² Though the representatives from Bristol pressed their petition, their arguments took a further blow when the Company of Armourers and Braziers opposed any increase in duty on imports, these already "being 22% on prepared metal and 30% on imported battery".³ Similar restrictions on the importing of many other goods such as copper and brass forced shortages on the English Tradesmen and Craftsmen which could not always be met by the infant English copper industries still in the throes of organising an industry which would be competent in its methods of manufacture, distribution and government. Erratic supply and demand at times left many thousands of tons of ore idle at mine-heads, due to unexpected price demands by either the smelting houses, the Miners themselves or indeed manufacturers. At one time (1730) the Cornish Mining Companies had a stock of 14,000 tons of copper bearing ore on hand due to a consolidated front set up by the English copper companies and other interested parties against the price of ore.⁴ This kind of confrontation was reflected in the price of copper in the form of sheet, plate, rod or wire as made available to the merchant and the craftsmen. So much so, that in 1726 Parliament were to hear a petition by the Company of Armourers and Braziers against certain fraudulent practices which were rife amongst the copper workers themselves. Examples of these abuses included making hollow handles for copper pots and filling them with lead, or indeed, wrapping copper around iron rod to make handles so as to make the pots heavier and, since the article was sold by weight, more expensive. Some pots

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1 Day J. p. 41.

2 J.H.C. Vol. 17, p. 128.

3 Ibid. p. 132.

4 Hamilton H. op cit p. 146.

would be sold at 18 shillings but contained only 8 shillings worth of copper. The profit of the copper-smith was the greater since he needed little or no copper rod and wire for his handles and rivets. Copper rod and wire was at times so expensive and difficult to obtain that it became accepted practice to use iron wire as a collar to strengthen the rims of copper pots, pans and other household articles. But even these were, at times (where possible) replaced by lead.¹ Parliament was told by the Company of Armourers that to charge for such collars and lead-filled handles (along with other deceptions, such as iron bottoms) weight for weight as copper, could not be tolerated since it eroded the profit of the honest copper-smith.

To what extent the above examples are indicative of the state of supply of copper and copper wire in England for the period 1720-30, is reflected in the Birmingham brass and copper trades which had advanced considerably by this time. Seemingly unaffected by inconsistent supplies of copper, often due to appalling road conditions and haggling between merchants and the various copper companies, the Birmingham craftsmen expanded their out-put so that by 1725 their skill had enabled the London trades in copper (and consequently the English copper industries) to carry competition into foreign markets. Certainly the home and colonial markets were now supplied almost wholly by English copper, and though some imports of copper and brass still trickled in up to 1745, most of the English wire and rod would by this time come from English wire mills and be made from English copper.²

The expansion of the English copper manufacturers, and the trading policies determined by them, appears to have been dictated by the development of the home industries in copper. Products such as copper wire could be looked upon as a standard commodity much used by the small industry and individual workshops in the manufacturing towns around England and on the Continent. The importance of such pre-manufactured materials, which included sheet copper, bolts and rods as well as wire, lay in those industries and crafts which demanded patience and

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1 J.H.C. Vol. 20, p. 826.

2 Hamilton H. op cit p. 290.

expertise, and not mass production. This side of business was to be conveniently left to the large companies which could invest in wire mills and rolling mills able to produce a consistently good product cheaply. Early trends in this approach to manufacturing demarcation were to be seen in examples such as the sheet rolling mills of the Dockwra Copper Company (1697)¹ and in the early part of the 18th century, the Mitcham Copper Works of Charles Parry.² Indeed, some early concerns, notably the Temple Brass Mills founded in 1700 by John Parry, were unable to define their position in the scheme of things. At first, this Company produced battery and rolled brass. But after 1720, with the ascendancy of the Birmingham trades and the obvious profitability of the market for copper goods, they began to turn to the making of copper products and by 1748 their out-put consisted mainly of copper pans and kettles.³ This example, though not exceptional, was uncommon in the history of the English copper manufacturing industries. Most enterprises established their markets and fixed their range of products. The Cheadle Brass Wire Company was a typical company which shaped its organisation and products to meet the demands of the copper trade; emphasis was laid on the production of raw materials suitable for working into finished articles. This company figures highly in the history of the copper wire industry though its early interests were in brass. In 1719, Thomas Patton, the owner of a small copper works in Warrington, began to develop his interests and a brass works was established at Cheadle in North Staffs.⁴ By 1734, wire mills at Alton-on-Churnet were set up and by 1755 a copper battery mill began operations at Greenfield in Flint.⁵ Thomas Patton and his partners declared that the new works at Greenfield were for "all sorts of work in copper fit for the copper-smiths - and for the making and finishing of copper rods such as are usually sold to the Guinea Merchants".⁶ This kind of

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1 Houghton J. op cit No. 258 dated July 9th 1697.

2 Hamilton H. op cit p. 107 and 344.

3 Hamilton H. op cit p. 151.

4 Hamilton H. op cit p. 149.

5 Hamilton H. op cit p. 150.

6 Hamilton H. op cit p. 259.

policy was maintained, for as late as 1790 new mills at Oakmore set up in the vicinity of the Alton works, were intended "to roll and slit brass and copper, and to draw thick wire and guinea rods."¹ Another concern of the company, which had been started earlier in the 1740 s, was that of producing "manillas", a copper bracelet or ring used as currency by some African tribes, especially those on the Gold Coast.² Both this kind of product and the manufacture of guinea rods, is clear comment on the companies interest and commitment to foreign trade.

As the markets for copper goods improved in both home and foreign trading, so the prospects for those companies mining and smelting copper gained in standing. New companies formed to supply the brass and copper manufacturing industries sometimes as a result of incentives for trade in a small locality. John Costa, a Forest of Dean man, had smelting works at Upper Redbrook - Bristol, as early as the 1680 s, when at the same time the English copper company operated at Lower Redbrook. When Costa died in 1718 his son, Thomas, took control but never matched his fathers' success in copper working which had been envied by even the London copper merchants. So much so, that some were induced into putting finance into the English copper industries, thus improving the overall prospects of all the other dependent industries.³ Thomas Costa died in 1739 and by 1742 the company was controlled by a Joseph Percival. Throughout its history, the works supplied copper to the local metal working industries and as the Bristol Brass Houses expanded, the Costa smelting works found larger markets.

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1 Hamilton H. op cit p. 150.

2 Hamilton ibid. - A recent paper suggests that certain manillas of German origin were manufactured for economy from the waste produced by copper smelters. Some 16th century manillas were preserved in-tact until 1948 and resemble in composition some waste deposits found on the sites of 16th century smelting furnaces in the Harz Mountains. See Otto W. V. "West African Manillas from German metal ore smelters -" *Erzmetall* - 29 (10) 1976 pp 447-53.

3 Jenkins R. op cit p. 317.

In 1746, new smelting works were founded at White Rock, Swansea.¹ Similar works appeared at Swinford, Wollard and Dublow near Bristol at and about this time, while the company, realising a need to stabilise its own production of copper in the face of competition, and to exploit the new markets for brass, opened in 1765 a brass works near its smelting houses at White Rock. One year before this, the company had lost Percival and by right of senior partner the company became John Freeman and Copper Company.² In 1750, the company produced 343 tons of copper,³ a significant contribution to the copper supplies of the Bristol Brass companies. One of the principal Bristol concerns at about this time, whose interest in copper contributed to the expansion of the copper wire industry, was that of the Warmley Company. This most important organisation in the history of English copper was founded in 1746 by William Champion and at its outset was known as William Champion & Company. At one time, Champion had interests in the Bristol Brass Company but was dismissed through bad feeling amongst the Directors of the old firm.⁴ Champion had experimented in brass making from the 1730s⁵ and in 1738 he was granted a patent for the recovery of zinc from zinc ores.⁶ Though this did not immediately bring any benefit to him, some eight years later he founded his own company and no doubt this was an act intended to exploit his own expertise in brass making using the new technique of zinc extraction from calamine. In setting up the new concern, Champion and his associates declared their intent to make "copper and brass spelter, and various utensils of copper and brass".⁷ Between 1748 and 1752 the company purchased approximately 3,000 tons of copper ore which

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- 1 Brown N. & Turnbull C. Century of Copper. op cit p. 55.
- 2 Hamilton H. op cit p. 154 and 250.
Day J. op cit p. 96.
- 3 Hamilton H. op cit p. 250.
- 4 Day J. op cit p. 78.
- 5 Raistrick A. Quakers in Science and Industry. Faber 1950 p. 193.
- 6 British Patent No. 564.
- 7 B.M. Add M.S. 36,221, f. 70 see also Raistrick A. op cit p. 19 and Hamilton op cit p. 156.

yielded 355 tons of copper - refined and workable.¹ Attempts to improve the efficiency of the process are seen as early as 1749 when Champion contracted to have a Newcomen Engine fitted into his works.² The Bristol Historian Ellacombe³ lists amongst the Warmley inventory for 1761 a windmill for stamping ores and five water battery mills with twelve hammers. From this, it would appear that insufficient water was to be had from Warmley Brook and we may infer that the engine was used to augment the head of water to the water wheels by recycling the water back to a mill pond.⁴ The wire mills, at Warmley were extensive. The "Wire House" contained slitting rollers⁵ and the wire mill itself was described as "large" consisting of 9 benches and 5 blocks capable of producing 100 rings of wire weekly.⁶ It was noted by Angerstein in 1745, that the Warmley works produced both thick and fine gauges of copper and brass wire,⁷ and apart from its direct utilisation by the company in the making of handles and rivets etc. for its "Guinea kettles", the importance of the trade in copper goods for Africa is reflected in the fact that in 1767, copper wire and rod was in stock in the form of Guinea manillas and Guinea rods.⁸ This information was compiled by Champion in 1767⁹ to assess the company's stocks, debts and

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- 1 Day J. op cit p. 223.
- 2 The engine was installed by a Joseph Hornblower who remarked of Champion "as to Mr. Champion, I think there are few mortals queerer. I hope I shall have done with them soon". - Raistrick A. op cit p. 195, see also Day J. op cit p. 85.
- 3 Day J. op cit p. 82.
- 4 Day J. op cit p. 80.
- 5 Raistrick A. op cit p. 195.
- 6 Day J. op cit p. 82.
- 7 Day J. op cit p. 81
- 8 Day J. op cit p. 90.
- 9 In April of this year, Champion obtained patents (No. 867 dated April 1767) covering considerable areas in the making of brass. The patent was important for its utilisation of Black Jack (Zinc Sulphide) instead of the traditional Lapis Calaminanis (Zinc Carbonate). In addition, the patent covered the removal of arsenic in copper smelt by using wrought iron either poled in or admixed, and the use of coal instead of charcoal used in annealing tubes for brass wire.

effects, a preparatory measure before attempting to develop the company further. However, by 1768 much opposition by other combines and firms concerned with brass, who feared that the Warmley Company could achieve a monopoly, forced a refusal by Parliament upon the company's request for a charter of incorporation.¹ The cost of fighting its opponents, and the heavy investment in new developments threatened to bring down the Warmley Company.² In April of 1768, Champion secretly attempted to withdraw his capital and upon being discovered by his partners was dismissed.³ Within the year Champion was bankrupt and one month after his bankruptcy, in March 1769, the Warmley Company was dissolved. Champion's inventory of 1767 had shown that the company had £94,000 of sales stock and £105,000 worth of equipment and plant.⁴ Within two years this had been effectively wiped out, so eliminating a founder of the English copper and brass wire industry. Warmley was never again to make copper wire or rod, the old works were to be purchased in 1769 by William Champion's old firm, the Bristol Brass Company. The impetus was lost however, and Warmley failed to re-muster the vigour that it had when under Champion's control.⁵

The Champion family played a leading role in the English brass and copper industries in much the same way as other Quaker families (e.g. Harford, Costa and Darby etc.); their efforts were seldom misdirected or lacking in enterprise. The Champions' are one example of a Quaker group which dominated the Bristol brass wire companies from the turn of the 17th century:- "Whatever field of metal-working is investigated, tin plate, iron, copper, brass or copper smelting, Quaker families occupy an honourable position as pioneers in the industry."⁶

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1 Day J. op cit p. 90.

2 Raistrick A. op cit p. 196.

3 Day J. op cit p. 93.

4 Day J. op cit p. 90.

5 Day J. op cit p. 93.

6 Raistrick A. op cit p. 214.

CHAPTER 4

NEW MARKETS AND NEW DEMANDS - 1750 - 1785

By 1750 it was still possible for the individual copper-smith or brazier to cater for all demands in copper-ware. However, as the number of different kinds of article increased, by way of competition from new specialised trades, it became increasingly difficult for individual craftsmen to possess every tool, machine and pattern necessary for production. Furthermore, the English copper industry had matured sufficiently, and it was soon to be heavily committed to expanding its interests in both manufactured and semi-manufactured commodities. In view of these changes, it might be concluded that the individual craftsman could expect diminishing returns from a shrinking market, saturated with utility goods from large scale manufacturers, and with specialised articles from the specialist craftsmen. That this was not the case may be attributed to the expansion of world markets at this time, which not only stimulated home production but also the home market, providing the impetus for trade to the benefit of both the artisan and his products.

The rapid increase in the home market and the considerable export trade in copper goods in the mid 18th century may be ascribed to both the early development of an organised brass and copper industry in England and the opening up of larger markets in the African and colonial trading posts. From 1731, the English East India Company exported largely raw material, but by 1751 this trade had been extended to include more manufactured goods in the form of rods, utensils, chains, sheet and bar.¹ One year before this new enterprise, the discredited Royal African Company had been succeeded by the African Company of Merchants constituted by an Act of Parliament. This particular company was to receive an

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1 'Copper Through The Ages . Copper Development Association 1936 p. 39.

annual subsidy from the Government¹ and became one of the instigators of the "triple-run" - the three-way passage of shipping which exchanged English goods at the African slave compounds for negro slaves who were then sold to the American plantation owners, leaving the ships' holds free for a cargo of tobacco on the return journey back to England and so to more trade goods.²

The kind of article supplied to the African trading posts is epitomised in the many terms used during the period to describe specialised barter and exchange goods intended for the African trading posts. Guinea rod and Guinea kettle etc., are excellent examples. Indeed, the influence of copper and brass is expressed clearly in some of the variety of names given to African trading posts of the 18th century. Perhaps the best example was the forming of the river town of Brass³ in southern Nigeria. The town received its name from the many items of copper (including rod and wire) and brass utensils imported in exchange for slaves, spices and olive oil⁴ (used in the Altena region for drawing wire). However, to concentrate on the expansion of African trade in the 1760 s, though not misleading, can be justified only in that it was clearly symptomatic of the general up-surge of trade throughout Europe at this time. Undoubtedly, the conflicts between rival trading companies in Africa during the expansion of commerce and trade in the mid 18th century is characteristic of a general trend toward economic expansion

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1 Encyclopaedia Britannica 13th Ed. 1926 Vol. 12, p. 205.

2 Ibid. Vol. 25, p. 222. It was claimed that the abolition of the slave trade (circa 1807) crippled the African company and it was dissolved in 1821.

3 It should be pointed out that even up to the beginning of the 19th century the word brass was ill defined and could often refer to copper as much as the copper-zinc alloy now known as brass. Traditionally, this material was known as Lattin or Latten.

4 i. Encyclopaedia Britannica op cit Vol. 4, p. 432-3.

ii. Some indication as to the question concerning the attraction for copper chains and other copper adornments so much valued by certain African natives, is given in a recent paper by Phillipson which shows a twisted copper wire necklace originating from a Bantu Iron Age. The fascination for copper - a rarely worked metal - appears, in all probability, traditional and in no way initiated by contact with European metal working. See Phillipson D. W. "The Spread of the Bantu Language" Scientific American April 1977 p. 110.

in the home countries. The territorial struggles of the European trading companies in Africa, India and elsewhere, such as the English and Dutch East India Companies, the African Company of Adventurers and earlier (in the 1730 s) the Ostend Company,¹ contrast an equally objective but muted struggle in the European trading markets. In both cases, copper wire and rod was an important commodity, mainly in the form of by-products: chains, armulets, rivets, hooks, cages, giltware, handles and nails. These represented traditional ways of utilising copper wire or rod. In a few short years, however, by way of a general technological improvement these uses were to be supplemented and in many cases superseded.

A significant contribution toward the further use of copper rod and wire was made in 1742. Thomas Bolsover, described by Hunter as "an ingenious mechanic"² while repairing a knife made of silver and copper, showed an uncharacteristic lack of competence (for an ingenious mechanic) and overheated the blade, allowing silver to flow over the copper tang. This accident gave a way of producing silverware at a cheap rate. According to Wyllie³, silver was three times as expensive during the period of Bolsover's accident as compared to the selling rate of sterling silver in 1900. Though Bolsover realised the value of his discovery, and was supported financially by a Mr. Pegge of Beauchief⁴, his activities in producing silver plate remained limited to the production of "buttons, snuff-boxes and other light and small articles".⁵ It was left to a Joseph Hancock, at one time apprenticed to Bolsover and Co.,⁶ to extend the trade and reputation of what became known as Sheffield (rolled) plate by extending plated wares to include candlesticks, teapots,

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- 1 Excellent histories of the expansion and trading positions of these companies may be found in various parts of the 13th Edition of the Encyclopaedia Britannica.
- 2 Hunter J. Hallamshire:- The History and Topography of the Parish of Sheffield . Ed.- A. Gatty, London 1869 p. 156.
- 3 Wyllie B. 'Sheffield Rolled Plate'. London 1908 p. 17.
- 4 Wyllie B. op cit p. 18.
- 5 Hunter J. op cit p. 156.
- 6 i. Hunter J. op cit p. 168.
 ii. Wyllie B. op cit p. 20.

waiters, and other sideboard decorations. To make much of this, he employed pre-drawn copper rod and wire which was worked and then dipped in silver to plate it.

This form of plating copper was far from being a new art. Burnishing and gilding copper was an early craft which may be traced back to ancient Egypt, if not before, whilst plated and gilt ware may be dated no later.¹ In general, a precious metal is worked as a surface overlay on a base metal and this is commonly found as copper.² Before Bolsover, plate ware was generally classed as gilt. Beckmann, in his treatment of Frederick Hegelsheimer³ in 1608, refers to his "works in copper gilt with silver and gold",⁴ while the act of dipping copper into another liquid metal is again an ancient practice. According to Plot, copper was plated by the Walsall braziers with tin. This was to give utensils a "lustre", to "preserve them from rusting" and to prevent "a taste of the metals to things boyled in them".⁵ Clearly then, Bolsover's technique was hardly new. Indeed, tinning and gilt work would not have been new to him;⁶ but the application of this technique, when applied to silver and copper, was new, and potentially profitable. Silver products made without solid silver could not fail to find a market. Accordingly, Bolsover proceeded to develop his discovery and in doing so enabled Joseph Hancock to enlarge the industry.

It was not Sheffield, however, which was ultimately to influence the use of copper wire in the making of Sheffield plate. Almost as soon as the technique

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1 Encyclopaedia Britannica 13th Ed. Vol. 22, p. 804.

2 Indeed, the basis also of enamel work.

3 Vide infra Ch. 1 p. 35.

4 Beckmann J. op cit Vol. 2, p. 227.

5 Plot R. A Natural History of Staffordshire, op cit p. 377.

6 Sheffield was well-known for gilt buttons.

became known in Sheffield, the Birmingham metal workers and craftsmen "early obtained a share in this lucrative trade".¹ One such Birmingham craftsman, George Whateley, a plater of silver,² perfected a method of making Sheffield plated wire, a material not only capable of being formed into beautifully artistic basket work but interestingly an item which was later to figure in electrical science.³ Sheffield plated wire basket-work epitomised the ultimate in craftsmanship. From 1768 (when Whateley patented his method) to about 1800, basket-work enjoyed a popularity;⁴ but this declined due to what has been described as a "lack of dignity"⁵ in the construction of such articles. Nevertheless, basket-work did thrive and credit is due to Whateley for its invention.

Before Whateley perfected his technique, plated wire - if made at all - was manufactured in much the same way as a plate ware known as French Plate. The French method consisted of overlaying thin sheets of virgin silver upon drawn copper wire. By the aid of heat and a burnisher, the copper fused with the silver by cohesion.⁶ Whateley however, saw both the deficiencies and the tedium involved in this technique and in two patents taken out on 8th November⁷ and 6th December⁸, 1768 he described an alternative, much improved method, for producing the same article. The November patent described a method of "Plating silver upon Mettall wire and drawing the same into wire of very fine sizes, both round flat and square".⁹ Whateley incorporated the old method of French plating by forming thick rods of

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- 1 i. Hunter J. op cit p. 156.
 ii. Hamilton H. (op cit p. 269) proposes the name of Taylor as that of the individual who introduced plating into Birmingham from Sheffield, while Prosser R. B. ('Birmingham Inventors and Inventions'. Birmingham 1881 p. 139) quotes William Rylands affirmation that Matthew Boulton introduced plating into Birmingham.
- 2 i. Veitch H. N. 'Sheffield Plate'. London 1908 p. 65.
 ii. British Patent No. 905.
- 3 Vide supra Ch. 6 p. 151.
- 4 Veitch H. N. op cit p. 72.
- 5 Ibid.
- 6 Veitch H. N. op cit p. 65.
- 7 British Patent 905.
- 8 British Patent 908.
- 9 British Patent 905.

pure copper of about one inch in diameter and working a strip of fine silver over its surface. He advanced the technique, however, by ensuring that the initial union between the silver and copper was improved by then drawing the composite "through three or four holes of the draw plate". This was continued until the silver was " - nearly closed round the mettall wire".¹ After this, the silvered rod would be heated - the silver being held against slipping by a binding of iron wire. The intense heat would "cement" or fuse the two metals and further drawing resulted in a long silver-plated copper rod or wire, which displayed no appreciable join on its surface. From this could be made basket-work in Sheffield Plate which utilised many gauges of silvered copper wire. According to Hunter,² between 1775 and 1801 the amount of Sheffield Plate examined at the Sheffield Assay Office was approximately 12,500 pounds (about 5.9 tons). Were we to assume only one third of this as being composed of silvered rod or wire, then 4,166 pounds was produced in Sheffield over 25 years. This is approximately 1.86 tons and taking an average wire diameter of 0.1 inches,³ some 116,000 feet (22 miles)⁴. An even greater quantity would have been produced in Birmingham.

To make wire such as this required drawing machinery. Indeed, to roll copper plate for the plate makers required extensive rolling equipment, and as the popularity of Sheffield Plate became the greater, so both Birmingham and Sheffield saw the rise of new companies concerned with sheet rolling and wire making. Both Bolsover and Hancock, the originators of Sheffield Plate, very quickly turned their attention to setting up rolling mills. Bolsover's main interest was to become steel; but Hancock maintained his involvement in the Plate trade, beginning with a small rolling mill worked by horse power in Union Street, Sheffield.⁵

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1 Ibid.

2 Hunter J. op cit p. 156.

3 No. 1 Standard wire gauge.

4 Calculated at a rate of .035964 pounds per foot. Data extracted from the tables issued by Glover & Company found on p. 150 of Bucknall-Smith A Treatise Upon Wire -. John Wiley - London 1891.

5 Wyllie B. op cit p. 21.

It is in this connection that his name appears in the 1787 Sheffield Directory.¹ (Horse power seems to have been first used by the company of Tudor Leader & Sherburn.² Henry Tudor was Thomas Bolsover's brother-in-law).³ Later, Hancock had water powered mills at Old Park Mill.⁴ There is little evidence that the production of silvered rod or wire quickly became a large scale manufacturing concern, it appears that for the early period of Sheffield plate at least, the drawing of wire sections was carried out on the craftsmen's premises. Plate 35 shows an example of a typical draw-bench to be found in the operation of drawing silvered wire. This kind of machine would be found in the workshops of many of the Birmingham and Sheffield plate-makers up to the 1860's when electro-plating displaced the older method almost overnight.⁵ It is interesting that the box beneath the draw bench shows a variety of draw plates - this is consistent with the possible 20 or 30 separate drawings necessary in making silvered wire from an original rod. Though tedious, the quality of the product made by such techniques warranted the time and effort involved. Not until 1785 was there to be an accredited alternative to the excellence of Whateley's technique. This method was invented under the aegis of the Sheffield firm of Wilks and Mottram. It consisted of drawing a silver tube over a copper rod. By excluding all the air during the process, this operation allowed immediate drawing and in effect reverted to the earlier methods of making French plate, but in the new method it was the act of drawing which fused the two metals. This type of plated wire achieved moderate success and was favoured by the plater, Mark Dixon.⁶

As the plating industries of Sheffield and Birmingham expanded in the 1760's

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1 Ibid.

2 Hunter J. op cit p. 168.

3 i. Wyllie B. op cit p. 25 strictly, Tudor married the sister of Bolsover's wife.
ii. Hunter J. op cit p. 168.

4 Hunter J. op cit p. 168.

5 Wyllie B. op cit p. 29-it is interesting however, that as late as 1853, the plater still held a lucrative trade sufficient to require that protection be gained for techniques in improving plate-ware. B.P. No. 2622 in the name of Stephen Barker was taken out in November of 1853 and covers the making of plate edging from silver plated copper wire.

6 Veitch H. N. op cit p. 71.

so too did many allied and subsidiary industries. Often this occurred as a result of new impetus in the copper industry itself. New deposits of copper had been detected by a prospector, Alexander Frazier, while searching for minerals at Parys Mountain in Anglesey.¹ One company that showed immediate interest was that of Roe & Company of Macclesfield which had formed in 1757² with four partners,³ of whom Charles Roe was the senior. Negotiations with the land owners in the Parys Mountain locality i.e. Sir Nicholas Bayley,⁴ Lord Uxbridge and the Reverend Mr. Hughes⁵ resulted first in Frazier sinking trial shafts and later Charles Roe taking a lease from Bayley for the Penrhyn Du Mine with an option on part of the Parys Mountain deposits.⁶ Frazier's results had shown how rich the deposits were and as Roe expanded his mining operations the richness of the find became more apparent. No mine shafts needed to be sunk, the ore was blasted from the side of the mountain and hand crushed by women and children.⁷ An open-cast mine some 200 yards long and 150 yards wide, with a depth of 40 yards, exposed one ore vein while another, approximately 500 yards long, was soon developed. The only mining machinery of any note appears to have been blasting powder and candles - one reference to the use of 17,000 lb of the former and 2,600 lb of the latter has been quoted.⁸ On average, the ores produced 40 lb of copper per cwt.⁹

Though Roe & Company had expended large sums of money in the enterprise,¹⁰

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- 1 Schofield M. "A Remarkable Century in the British Copper Industry" *Metallurgia* 72 (429) p. 25 (July 1965).
- 2 i. Hamilton H. op cit p. 157.
ii. Webster-Smith B. *Sixty Centuries of Copper*. C.D.A. 1965.
- 3 Hamilton H. op cit p. 157 - Robert and Brian Hodgson and John Walker made up the other three.
- 4 Schofield M. op cit p. 25.
- 5 Hamilton H. op cit p. 152.
- 6 Schofield M. op cit p. 25.
- 7 i. Hamilton H. op cit p. 153.
ii. Schofield M. op cit p. 25.
- 8 Schofield M. op cit p. 25.
- 9 Ibid.
- 10 Hamilton H. op cit p. 152.

the most significant contribution toward development of the Anglesey copper mines was made by Thomas Williams who quickly brought a smelting works to the Anglesey site and was finally to take control of the two principal mines in the area, forming the Parys and Mona mining companies. Initially, smelting took place at Amlwch at the tip of the Isle of Anglesey.¹ Further processing at Swansea took the out-put of the Parys mine;² other ore concentrates went to Liverpool and Greenfield.³ Williams was later to ship his ore to St. Helens in Lancashire to exploit the coal fields there.

One of the by-products of the Parys mine was "shaft water" which was rich in dissolved copper, "sulphureous acid" (H_2SO_4) was found to dissolve copper from the ore veins and when this was discovered it was quickly utilised.⁴ The water was run into pits and scrap iron recovered the copper by deposition. While this enabled a further recovery of investment, the copper selling at between £25 and £45 per ton,⁵ it was in effect a labourious method since it required the manual removal of a copper deposit from an assortment of iron made items including anchors, pots and hoops. This was greatly improved when 4ft iron sheets were used resulting in a marked reduction in labour costs.⁶ However, the most interesting application of these copper-rich waters was in "soaking" ships' timbers, a technique designed to deposit copper on exposed metal parts,⁷ and impregnate the wooden hull with copper.⁸ This was done in order to prevent infestation and

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1 i. Hamilton H. op cit p. 153.

ii. Schofield M. op cit p. 25.

2 Hamilton H. op cit p. 153.

3 Schofield M. op cit p. 26.

4 Schofield M. op cit p. 26.

5 Ibid.

6 Ibid.

7 In particular, iron nails used in the process of "filling" the surface of the hull. Later, after the success of "coppering" was established, "filling" with iron bolts and nails was replaced with identical parts in copper. Vide supra Ch. 4 p.114.

8 Schofield M. op cit p. 26.

contamination by marine weeds and molluscs, and above all the ship worm or Teredo.¹ Naval vessels were sent to the area and "docked" in a pool of mine water, and though a moderately successful technique, the scheme was not to be extended to any great scale since it was overshadowed by the results of a parallel experiment. This was the first sheathing experiment in copper to be tried on ships' hulls. Its success, took away much of the business for soaking ships in the Parys Mine waters; but more was to be gained in the greater demands for copper, thus creating a greater market for mined copper than ever before.

On Monday 9th November, 1761 a report was issued that:-

"The sheathing of the Alarm Frigate was finished. It is of copper, the first trial that ever was made of this kind of sheathing; it is very neat, not heavy nor very expensive. She is designed for the West Indies."²

The warmer waters were notorious for rotting ships' timbers and this would be a good test for copper sheathing. Indeed, the intention in experimenting with copper clad hulls was to ensure not only that Naval vessels could maintain the integrity of their timbers, but also, and equally important, their speed.³ Fouling of the bottom introduced drag as the ship moved through the water and the loss of a ship in action, due to loss of manouverability or speed, was as expensive as having to replace the hull or, worse, the entire ship following the invasion of the marine wood-borer, the ship worm Teredo. The main concern, was to find a way of permanently maintaining a ships' hull - having achieved this, other benefits might follow, and this was a problem long recognised by Naval architects. Seventy four years before the "Alarm", Thomas Hale had taken out patents on

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- 1 Nepean Longridge N. The Anatomy of Nelson's Ships. Percival Marshall 1955 p. 54.
- 2 'Notice" Gentlemans Magazine (31) 1761 p. 533.
- 3 Bugler A. H.M.S. Victory. H.M.S.O. London 1966 p. 164.

"The manufacture of milled lead for sheathing and preservation of ships -".¹ Thus, the "Alarm" was the culmination of many serious attempts at protecting ships' timbers. Hales trials were moderately successful² as were the Parys water tests. But when the "Alarm" returned to Woolwich in 1763 it was clear, after inspection, that the attempts in "preserving it against the worm" were the most satisfactory solution so far attained.³ The experiment had included the testing of two types of fastening for the copper-plates covering the hull and these consisted of both iron and copper nails. The two year trial showed the advantages of using copper fastenings. The plates pinned by the copper nails remained clean while those parts held by iron "were so corroded and eat - that they could not have continued -"⁴. These results were clearly favourable and both copper nails and copper bolts in preference to iron were quickly in service with the British Navy. In 1776, some twelve vessels - frigates and smaller ships - were sheathed with copper, and by 1781 Rodney was to sail to relieve Gibraltar with a completely coppered fleet.⁵

The technical problems in sheathing ships chiefly concerned the three important components; rolled copper, nails and bolts. Of these, the first had long been an established product; but the making of the copper nails, and a little later copper bolts, were soon found to be capable of improvements. Whereas in 1761, the "Alarm" had incorporated copper nails which had been supplied by outworker nailers and involving a lengthy slitting, drawing and heading process, marked improvements were later introduced by two Birmingham inventors

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- 1 British Patent No. 254 dated 13th August, 1687. This patent was initially under the name of Howard and Watson, taken out in 1682 it was protected by an Act of Parliament. Hale and his associates were the successors and improved upon it.
- 2 Prosser R. B. Birmingham Inventors and Inventions. Birmingham 1881 (privately printed) p. 118.
- 3 Navy Board Out-Letters (to the Admiralty) A.D.M. 106/2195, dated 31st August, 1763.
- 4 Ibid.
- 5 Singer et al A History of Technology. Vol. IV pp. 579-80. Oxford 1958.

almost simultaneously. The first of these improvements was made and described by William Collins, a button maker, manufacturer and inventor of some note in Birmingham,¹ who on the 29th January, 1783 patented a method of "Making and preparing bolts used for fastening the timbers of ships together -".² Plate 42 shows Collins' method of drawing bolts described as being pure copper (or of copper plated iron - plated to prevent "decay by salt water").³ Collins' method was unique in that it employed not only the traditional draw plate but two roughened rollers which, besides helping to reduce the rod or wire, applied traction to draw through the copper rod. Collins' method could draw fine and coarse gauges of copper wire or rod and was universally applicable in the dock yards. Smaller fastenings, such as those used to tie down copper sheathing, could be cut from lengths drawn by Collins' machine as too could the larger bolts used to pin the timbers themselves. Here, however, a special machine was used; and this particular apparatus was invented by the second Birmingham manufacturer, John Westwood. The patent for this invention emphasises a technique designed to "harden and stiffen copper -"⁴ and was issued some two months after that of Collins'. Strictly speaking, Westwood's patent carried only a general description of a rolling process utilising a pair of unmeshed bevelled rollers. Plate 41 shows that his intent was to form copper into rods of a variety of shapes. Ultimately however, his interest appears to have lain in the hardening and stiffening of copper bolts and whatever the generality of his patent, it was this that gave the method its fame. The rolling evidently cold worked the copper, and bolts made from it were better able to be forced through timber than those which had been battery forged or cast and contained faults. Indeed, though the copper bolts were

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- 1 His patents included methods of button making and forming metal tubing, besides that of a number of patents related to sheathing and fastening ships' timbers. See Prosser R. B. op cit p. 55, 86 and 120.
- 2 British Patent No. 1388.
- 3 Ibid. p. 2.
- 4 British Patent No. 1398 - filed 12th March, 1783.

favoured for their durability in sea water, they were less easy to install, the act of driving them in being often tedious and difficult. Some bolts, in the deadwood aft of a ship might measure one half inch in diameter and be some six foot long. The bolt would ideally follow a bore hole formed by an auger but more often than not, it would split or shear long before it had been driven home and clenched over a tie-plate.¹ The method employed by Westwood formed a stiff bolt with a clean surface. It was a technique which was capable of producing large quantities of the required product. It is interesting that Westwood specified both the production of regular and irregular rods of diameters ranging from five inches to one half an inch. Clearly, Collins' machine began its usefulness with the smaller gauges - an area where Westwood's machine left off. This is perhaps some explanation of the success of both machines in the dockyards. Indeed, the two men combined their efforts so that eventually their products became known as "Westwood and Collins Patent Copper Ship Bolts" claiming to be "harder and stiffer" and able to be driven "better than iron bolts -".² It was said by Thomas Williams (when a witness to a Parliamentary enquiry into copper monopolies in 1799) that the earlier work of Collins and Westwood was that of "two ingenious artists" who had, along with Williams "found out the method of making copper bolts far superior to the very best iron ones ever made".³ Williams' enthusiasm for his copper interests clearly promoted his generous comments on behalf of the two Birmingham men. Collins

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- 1 Initially the copper bolts were wasteful and consumed much time through either splitting or bending. Sometimes a segmented iron tube was employed to overcome this by acting as a retrievable guide as the bolt was driven in. See Nepean Longridge N. op cit p. 28.
- 2 Gores Liverpool Advertiser. 7th January 1784 - "Patent Copper Bolts".
"Westwood and Collins Copper Ship Bolts".
- 3 Reports of the House of Commons "Copper and Copper Trade" Report dated May 7th 1799 - J.H.C. Vol. 10, p. 653. On page 660 of this report Williams talks of the:- "experiments (were) made to form compound cast metal into bolts for the purpose; all of which were found too brittle and unequal to the tight drifts required. But after great pains and labour with two ingenious artists of Birmingham, we found out the method of making copper bolts far superior to the very best iron ones ever made." With regard to the Parliamentary Reports on copper monopolies see also Langford J. A. A Century of Birmingham Life. (Birmingham 1868 Vol. I, p. 326-9, 354, 355, 348-9. Vol 2, p. 18-21, 86, 87, 90, 91, 110-113, 464, 465) for an excellent insight into the publicised efforts of the Birmingham metal workers to escape copper monopolies and legislation.

was in the employ of Williams as a technician¹ and Collins' partnership with Westwood extended Williams' control over the greater part of the copper supplies to the Navy Board. Williams' Agent in this respect was William Forbes who acted as London Agent and was principal contractor to the Navy Board.² He had, himself, invented bolt-forming rolls³ but its worth was overshadowed by the machines of Collins and Westwood. Williams made much of his employees "pains and labour" and since he included himself in their achievements he raised his own prestige but in fact neither Williams, Westwood, Collins or Forbes could claim originality and they owed much to the work of John Purnell whose patent for grooved rollers (intended for making "-ships bolts - rods and wires") had been taken out some seventeen years previously.⁴ Nevertheless, both Collins and Westwood did much to further the mechanisms by which high grade copper rod and wire might be made and this contribution remains significant in the history of the copper wire industry. Thomas Williams was later to be heavily committed to supplying copper sheet, nails and bolts to government dockyards both in England and other European nations.⁵ In this respect also, we find that Matthew Boulton was as significant in his activities in promoting and defending the English copper industry as Williams was in maintaining his own interests. Indeed, both men were known to each other and at one time (June 1785) Boulton was to say of Williams that "he had done more for the copper trade than all the other drones in it".⁶ At first, neither Boulton nor

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- 1 Harris J. R. · The Copper King. Liverpool U.P. 1964 p. 48.
- 2 Knight R. J. B. "The Introduction of Copper Sheathing Into The Royal Navy 1779 - 1786" - Mariners Mirror - LIV 1973 p. 305.
- 3 British Patent No. 1581 filed 29th July, 1783.
- 4 British Patent No. 854 1766, see also Chapter 1 p. 58. The same sentiment is shared by Prosser R. B. op cit p. 127.
- 5 Boulton to Watt, June 6th 1785. After Hamilton op cit p. 169.
- 6 Ibid.

Williams directly involved themselves with the supply of copper ores, or manufactured copper, for shipping. Williams was no doubt first aware of the usefulness of copper in this respect when the occasional ship was soaked in copper-rich waters surrounding the Parys Mountain. At one time, Boulton acted as a mediator between Williams and the Associated Smelters who had disputed certain of Williams' marketing rights, and it was due to Boulton that Williams received offers of settlement which amounted to unfavourable terms as far as Williams was concerned.¹ This was not in the least suprising however, since Boulton was at this time (1781) connected with the Associated Smelters.² Williams, however, was not to be deceived and refused to accept all terms. From this point, they came to know one another and doubtless gained a mutual respect for each others abilities. When the Cornish copper mines eventually came to compete with the Anglesey mines in 1785, Williams persuaded Boulton to gain some interest in a new company which was to be floated in an effort to control copper production and consequently the market price. It was hoped that a price standard could be set up and purchase prices would stabilize.³ The Cornish mines had met with severe difficulties due to fluctuating markets and the new company - The Cornish Metal Company - brought all the mine owners, and their smelting and manufacturing facilities, under one management. Ultimately, the formation of this company defended Boulton's interest in preserving his market for pumping engines in the Cornish mines⁴ and gave him a controlling interest in the source of supply of copper for the Birmingham trades. Furthermore, his associate, Williams, found himself controlling a major share of the English copper industry.⁵ Thus, in a steadily increasing market, such as ships sheathing, both men would be aware

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- 1 Hamilton H. op cit p. 161.
- 2 Ibid.
- 3 Schofield M. op cit p. 26.
- 4 Hamilton H. op cit p. 167.
- 5 Schofield M. op cit p. 26.

of the potential for, and the importance of, a variety of copper products such as wire, rod and sheet used in the dockyards, and to this end the 1780's passed with both men turning over an increasing proportion of their production facilities to sheet, rod and wire. Williams and his associated Anglesey company slowly dominated the copper wire, rod and sheet industry for naval and mercantile marine. The Parys Company's Holywell works consisted of some three plants: a rolling mill, a copper forge and a copper-wire mill.¹ Though the main concern of the wire mill was in drawing copper bell wire^{*} and chain wire etc., it also drew wire for "nails of the common sort".² Copper strip was also drawn so that the firm's nailers could make specialised nails and tacks,³ some of which would be destined for "filling" or "studding" ships' hulls. This was a common technique which dispensed with the problem of fitting copper sheet on irregular parts of a ships hull and depended on covering the entire surface with broad headed copper nails.⁴ Like Holywell's additional interests, which covered the manufacture of manillas for the African trade, as well as components for mercantile and naval needs, other companies (e.g. Roe & Company) attempted to infiltrate the newer markets by emulating Williams' energetic conversion to large scale rolling and drawing mills. It was however, very difficult to match his pace and zeal. In 1788, Williams bought the Temple mills at Great Marlow (Bucks)⁵ and within a short time they were manufacturing copper pans, bottoms for distilleries (brewing vats) and a great deal of sheathing (copper sheet) rods, nails, bolts and

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- 1 Harris J. R. op cit p. 178. After Lentin A. G. L. Briefe uber die Insel Anglesea (Liepzig 1800) 8th letter p. 79 et seq.
- 2 Knight R. J. B. op cit p. 302.
- 3 Some were made to hold fast by forming a re-entrant groove - "screw nails". See Harris J. R. The Copper King. op cit p. 49.
- 4 Knight R. J. B. op cit p. 302, and Harris J. R. The Copper King. op cit p. 49, and Harris "Introduction of Sheathing" op cit p. 553.
- 5 Hamilton H. op cit p. 152. Williams purchased the mills from a George Pengree.
- * Vide supra p. 121.

wire.¹ Much the same was produced by the Eaton and Bosley mills of Roe & Company, but in this case the copper sheet, bolts and wire were supplemented by some brass production used in the making of brass wire.² An indication of the size of the market at this time is given by the fact that the Cheadle Company also continued to produce, at their Oakmoor rolling mills, a similar range of products - copper sheets, thick wire and rods.³ On the face of it, there seems to be little evidence that price fixing and monopolistic practices in the copper industry were being reflected in the out-put of the operational mills in England at this time. It is true however, that many companies experienced severe difficulties in maintaining copper supplies and a free market for their products. In an attempt to evade price fixing (by monopolies) and inconsistent supplies, some companies began importing copper. Roe & Company, for example, opened mines in County Wicklow, while at one time James Watt remarked icily on the plight of his partner, Matthew Boulton, after he had found an empty warehouse in Birmingham - "the company cannot find sales, yet their warehouse is empty of the most saleable copper -".⁴ This was, however, exceptional in Boulton's general business activities; his Soho works, some two miles north of Birmingham, rarely found itself idle. Indeed, Boulton could find many alternative markets for rolled copper sheet which, if not used for shipping, would ultimately turn easily to the minting of coinage or the making of buttons or buckles etc.⁵

Seemingly unaffected by unstable conditions in the copper industry (and at

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1 Hamilton H. op cit p. 258.

2 Lysons D. *Magnum Britannia*. 2 Vols., London 1806, Vol. 2, Part 2, p. 427.

3 Hamilton H. op cit p. 151 and 259.

4 Hamilton H. op cit p. 177.

5 *Encyclopaedia Britannica* 13th Ed. 1926 op cit Vol. 4, p. 324.

times inconsistent demands for copper wire contributed to this instability) copper wire was becoming a very important commodity, increasingly in demand. Apart from the many traditional uses, and by the 1770 s this might now include insets for copper plate engraving¹ and calico printing blocks,² it would by this time also be seen in bell hanging, where very long lengths of copper wire operated mechanically linked pulleys for ringing bells in servants' quarters from remote drawing rooms.³ Copper was cheaper than brass and much more durable than iron in this application; iron wire was untrustworthy due to inevitable rusting problems. Nevertheless, copper wire was far from infallible in this respect. I find an interesting observation from F. Sherwood Taylor:-

"- a maze of bell-wires traverses the house; at each corner they connect up to little cranks, which pull on other wires and finally tug at hanging bells in the kitchen. In the sitting rooms the wires are pulled by thick fabric cords or strips which often break away and which collect dust, as indeed does the whole bell system. The wires provide good cover for spiders and avenues of travel for mice - which often ring the bells and cause false alarms."⁴

Copper wire then, was useful both in long lengths and on the contrary, in very short lengths when formed as rivets for a variety of domestic utensils. An old market for copper rod and wire, copper rivets were now becoming much more common, and this is attributable to a number of factors, not least of which was the technique perfected by the Birmingham inventor, Richard Ford.

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- 1 Archdeacon J. A Chronological Series of Engravers from the Invention of the Art - . Cambridge 1770 p. VII et seq.
- 2 The Cyclopaedia of Useful Arts and Manufactures - Ed. Charles Tomlinson, Virtue and Co., 1860 p. 912.
- 3 Ibid p. 912. See also Fahie J. J. "An Episode in the Early History of the Telegraph" Electrician (23) Vol. X, April 1883, p. 6 "- one would be inclined to believe from the comparison with bell hanging, the means employed comprises wheels, levers and such like". (For further references to bell-wire and bell hanging, see The Cyclopaedia of Useful Arts and Manufactures op cit p. 552 and Ch. 4 p. 49 . Ref. 1).
- 4 Sherwood Taylor F. A Century of Science. Heinemann, 1941 p. 190. It should be noted that here the facility is described at a stage of development as it probably was in the second third of the 19th century.

In 1769, Ford described a method of "rolling silver, copper - with the same rollers in one operation - drawing wire by wheels and a pinion - and raising by a stamp and press, scale pans, saucepans, warming pans, basins, plate covers, kettles, ladles and various other things of silver copper and other metals."¹ Domestic utensils of copper were already to be seen incorporating handles and rims of copper rod and wire - but now the effective mass-production of copper-ware was facilitated by the use of pre-made dies which could stamp out pre-formed sections from copper sheet. The idea had been tried successfully in the minting of coin,² while some eight years before Richard Ford's patent an Exeter Watchmaker, George Sanderson, had applied the idea to pressing out parts for clocks and watches.³ Much the same method had also been made known in a patent granted to a London toymaker, John Pickering.⁴ Ford's work, however, enabled a simple semi-manufactured item - rolled copper sheet - to be stamped into sections which, with little extra work, would produce a completely finished article. However, in Ford's method it was not common to attempt a totally finished article in one operation. Often, the handle for say a saucepan, was not pressed out at the same time as the bowl. Consequently, the handle would be pressed separately; the completed article consisting of a pressed bowl and separate handle, the two being finally riveted together. The rivets were generally of copper, in copper-ware, being formed from the rolled or drawn copper rod, which after being headed at one end would be cut off at the desired length, leaving the other end blank. Thus, for every stamped copper pan a certain quantity of rivets, by way of copper rod or wire, was necessary. Exceptionally, a wooden handle was sometimes fitted which

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1 British Patent No. 935 dated 23rd December, 1769.

2 Prosser R. B. op cit p. 134.

3 Ibid.

4 British Patent No. 920 "A New Method of - Working Metals - by a machine consisting of an oblong square frame, with two rods in which a moving forcer is worked upon a striking block with a die fixed thereon -". See Prosser R. B. op cit p. 134.

often utilised a retaining bolt through the centre of the handle. The bolt head would either itself be riveted to the bowl or it might enter from the inner side of the bowl wall. In any event, it could in itself be of copper, starting life as rolled or drawn rod or wire.¹ Finally, it should be stated that though copper rivets were far from new in the making of copper utensils,² Ford's patent transformed the making of copper-ware into an easy process, and this greatly increased the quantity of copper rod and wire used in the form of rivets. Ford achieved success in his ventures being described somewhat later by Prosser as "a very ingenious and prosperous manufacturer".³ To him, the copper wire industry owes a small but significant acknowledgement - the principles applied by him are still in use today as, indeed, are copper rivets. The importance of this, to Ford, is in some way expressed by the fact that his patent describes the making of rolled and drawn rod and wire before that of his method of stamping and pressing.⁴ Handles, rims and rivets were thus made by his drawing method.

The process of stamping made way for the high volume production of many articles important to the Birmingham trades. New trades quickly appeared, based on the making of the dies and stamps themselves.⁵ The trade of die-sinker became known, as too did that of stamp and press maker.⁶ Since rolled sheet copper was now readily available, this made the stamping and pressing out of many previously hand-worked articles that much simpler. Of these items, a number would still employ quantities of copper wire. Buckles were one type of article, and buckle-making was a very important trade to Birmingham as it had been to

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1 Various utensils were examined by the author at the Shaftsbury Museum (Dorset) and were authenticated by the curator.

2 Vide infra Ch. 2 p. 84-88.

3 Prosser R. B. op cit Ch. XXVI p. 134.

4 British Patent No. 935 p. 2 (10-20).

5 Hamilton H. op cit p. 268, 347.

6 Ibid.

Walsall during Plot's visit in 1686;¹ but now the Birmingham trades enjoyed the hey-day for the fashion in shoe and belt buckles. In 1770, fifty-eight buckle-makers worked in the town² and by this time many utilised Ford's method for pressing out the buckle frame, which was often embossed or ornamented. The mechanism for holding the strap, which was called the 'chape'³, is of greater importance to this study since it depended much on copper wire. The 'chape', as in modern buckles, consisted chiefly of a hinged cross-bar affixed to the buckle frame, from which protruded a short rod (or thick wire) of metal which retained the strap by protruding through an eyelet in the strap. In many cases, especially where the buckle was gilt, both the buckle frame and the 'chape' were of copper. Thus, copper rod and/or wire was much used in the hinge and catch of the 'chape' and was made complete before the whole article was plated. The art of chape-making became a distinct trade by the 1780 s and in 1781 Daniel Winwood "buckle chape-maker" patented what became known as "joint wire".⁴ Winwood made buckle hinges by soldering short tubes of very small bore - infact hollow wire - through which the hinge pin was passed. This method however, could well have been French in origin since the word 'charnière' was used to describe the technique; charnière being the French for hinge.⁵ The specification also describes the turning over of the buckle frame to form a hinge, but this was in keeping with traditional methods.

The most basic method for manufacturing the buckle frame and chape appears to have been perfected by William Playfair (brother of Professor John Playfair) who obtained patents in 1785⁶ for the making of buckles by rolling rod through plain or embossed rollers. In this technique, the metal was formed by the rollers

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1 Vide infra Ch. 2 . p. 88 .

2 Prosser R. B. op cit p. 53. Hamilton (op cit p. 266) claims the number was forty-four but offers no reference to this, while Prosser quotes Adams's Directory of Birmingham Trades .

3 Prosser R. B. op cit p. 49.

4 British Patent No. 1293 dated 28th May, 1781.

5 Prosser R. B. op cit p. 50 - see also the work of Wollaston, Ch. 6 p. 148-150.

6 Ibid.

and cut off at a desired length whereafter it was bent round to form the buckle frame, and then soldered. Indeed, plain frames and the chapes were simply drawn through dies. Those buckles to be plated were made of copper or copper alloy rods.¹

The importance of copper and copper wire in plated buckles is indicated by the applications for patents for improvements in buckle making by those involved in plating. During the period 1779-1790, twenty-seven patents for buckles were taken out (only three more were issued for the last ten years of the century)² and of these, some of the most important were taken out by "Platers".³

The decline of the buckle trade, and the subsequently small reduction in copper consumption, has been attributed to the tying of footwear by shoelaces.⁴ In 1791, a petition to the Prince of Wales described the depressed condition of the buckle trade setting out the change in fashion which had affected some 20,000 people concerned with the trade in Birmingham, Walsall and Wolverhampton.⁵ Royal patronage produced a slight revival but of the fifty-eight Birmingham buckle-masters, one hundred and twenty seven Wolverhampton buckle-masters and the two hundred and eighty three in Walsall, the great majority had failed by the turn of the century. By 1880, Birmingham had only two buckle-tongue makers (wire and rod working) and four buckle-makers, while in the whole of Staffordshire there were only twenty five buckle makers, three buckle-tongue makers, two buckle-platers and one buckle-tongue plater.⁶ (Interestingly, the copper based

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1 Prosser R. B. op cit p. 51.

2 Prosser R. B. op cit p. 49.

3 Ibid.

4 Hamilton H. op cit p. 301.

5 Hamilton H. op cit p. 301, 302. See also Prosser R. B. op cit p. 48, 53.

6 Prosser R. B. op cit p. 53 (Post Office Directory for 1880). It is interesting to note that Hamilton (op cit p. 269) quotes figures claiming that at least ninety-five platers worked in Birmingham in 1797, and of these a number are listed as manufacturers of plated wire and buckles. As early as 1830, it was said that "During the great part of the last century the manufacture of shoe-buckles and knee-buckles was carried on here" (Birmingham) "- to an amazing extent; but, owing to mutation in fashion this branch of trade is now extinct." Yates G. An Historical and Descriptive Sketch of Birmingham - With Some Account of its Environs. Birmingham 1830 p. 80.

buckle still had some importance). It is fortunate, then, that although the buckle trade decayed rapidly, the effect was little felt by the copper industry. The amount of copper wire and rod drawn by the trade was comparatively small and seldom made available outside the realms of the article or the buckle shops themselves.

In evaluating those patterns of change and development experienced in wire-making from the time of Theophilus, it is noticable that the extension of the range of applications for wire stimulated the establishment of more wire-mills to provide for them. This, in turn, influenced the formation of stable supply industries which enabled consumer trades to expand. Steady consumption tended to reduce costs and expand the range of applications, but it also invited restrictive and monopolistic practices. Nevertheless, it has been shown that the mutual relationship between the capacity to consume wire and the facilities to produce it were not in themselves independent of the circumstances of specialist trades. The minor wire consuming trades survived (p. 104) because of economic growth and the development of trade, and they did not necessarily place any reliance or dependence on large wire mills. The mills, in turn, flourished through larger (specific) outlets for their products. The supply of raw material to the trades was often incidental to that output consumed by their principal markets. The exploitation of fresh mineral resources, and the opening of new mines, was often undertaken to make available copper for those mills supplying particular markets such as shipping. While the tradesmen could make their own wire their fortunes did not greatly concern the large copper manufacturers.

The similarity in the commodities produced by one mill as to those of another is indicative of market orientated production which affected manufacturing flexibility. Flexibility in the system was due to the numerous applications of a staple product; copper rod and wire found many uses, and because it was a basic item common to many trades before large mills made it available, it was something not necessarily treated as an item to be supplied by an external source. The philosophy of remaining self-sufficient, common to many specialist trades, could not greatly affect the wire mills - they had developed to satisfy bigger markets. Wire production and consumption

were tied closely together but both answered to the prevailing economic and trading climate. Only serious political or economic disruption produced (transient) changes. The overall trend was to be a maintenance of economic growth and an identification of the copper industries overall direction. In determining how this identity was modified it is worthwhile giving a detailed summary of the patterns of change that surrounded copper wire and transpires in all that has been said so far:-

- a. 1 Small scale manufacture for particular applications (religious ornaments, weapons, some domestic utensils and clothing fastenings).
- 2 Development of use of copper utensils, leading to larger application of copper wire.
- 3 Development of new trades and the supply of wire as a staple commodity.
- 4 Rise of imports to supply raw material for trades and wire-making.
Rise of imports of pre-manufactured copper wire.
- b. 1 Development of competition and free trading with increase in importation.
- 2 Expansion of trade and development of further applications of copper wire.
- 3 Opening up of English mines and English mills.
- 4 Expansion of supply industries. Development of manufacturing (commodity) industries.
- 5 Expansion of home industries reduces import levels.
- c. 1 Attempts to make home produce of copper and copper articles more competitive in foreign markets. Rise in consumption of copper wire.
- 2 Consolidation of industrial strength, markets and applications.
- 3 Establishment of organised industry and stable trading climates.
- 4 Expansion of foreign markets and specific manufacturing exercises for export trade. Creation of stable growth patterns in the wire industry - mutual stimulation between supply and demand.
- 5 Influence of special groups in industry (i.e. Quakers etc.).
- d. 1 Improvement in wealth and general industrial strength as a result of general economic expansion.
- 2 Continued development of new applications as a result of technological and economic development.
- 3 Efforts to improve manufacturing methods for wire to reduce costs, improve efficiency and expand output.
- 4 Larger markets and greater production call for an expansion of raw material resources.

- 5 Industrial organisation leads to monopolistic practices i.e. price fixing.
- e. 1 Deliberate market orientated production i.e. development of production facilities for the direct supply of one consumer (e.g. shipping).
- 2 Stable growth, standard commodity range leading to product similarity in wire mills.

The creation of a trading position where copper wire was one item amongst a number of staple commodities, (acting as a foundation for consumer products) took many years. This evolutionary process resulted in the establishment of 'standard applications' for copper wire where wire consumption could be expected to remain steady. These applications, found in the traditional crafts industries and trades, had and would serve as a basis for a good trade in copper rod and wire. However, staple commodities such as chains, rivets, handle shafts, cages, spindles and nails were products soon to be over-shadowed in their consumption of wire:- shipping, plating and stamped domestic ware had already by the 1780 s offered the prospect of a greater consumption of wire. However, by this time a new, and what was to become a much more important application, was emerging - the consumption of copper wire as an electrical conductor.

CHAPTER 5

COPPER WIRE - ELECTRICAL SCIENCE AND THE DISCOVERY OF A PREFERENCE

Writing in 1777, the electrician Tiberius Cavallo (1749-1809), pointed out that "In order to guard edifices or ships from being damaged from lightning - it was judiciously proposed by Dr. Franklin to raise a metallic conductor -".¹ As it transpired, these conductors were to be more often than not made of copper since:-

"Copper would do much better than iron; it being a more perfect conductor."²

This conclusion, accepted by Cavallo and many of his contemporaries, enabled him to state that as protection against lightning:-

"On board ships a (copper) chain has often been used, which on account of its pliability, has been found very convenient; but as the electricity finds great obstruction in going through several links, for which reason chains have been actually broken by lightning, their use has now been almost entirely laid aside, and in their stead, copper wires a little thicker than a goose quill have been substituted and found to answer very well."³

Why lightning conductors in general, and copper conductors in particular, became widely used (albeit with much controversy over their effectiveness) is a question well answered by reviewing some instances which illustrate the need to protect buildings and ships from lightning.

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- 1 Cavallo T. A Complete Treatise of Electricity - in Theory and Practice -. E. & D. Dilly, London 1777 p. 76. See also Franklin B. "Means of Preserving Buildings, Ships etc., from Lightning" (1749) reprinted in: Steps in Scientific Tradition. Editor R. Westfall - J. Wiley 1968 p. 314.
- 2 Cavallo T. op cit p. 79. See also Young T. A Course of Lectures on Natural Philosophy. 2 Vols, J. Johnson 1807 Vol. 1, p. 715 - "A lightning conductor should be of ample proportions and where smallest of copper since copper conducts electricity more readily than iron."
- 3 Cavallo T. op cit p. 81, 82. Iron chain was, it seems, as common as copper. In 1829 it was reported. (Library of Useful Knowledge, 3 Vols. Baldwin & Cradock, London 1829, Vol. 2 p. 60) "- for the protection of ships, chains made from a series of iron rods linked together are, by their flexibility, conveniently adapted."

Although earlier data on the matter is wanting, between 1793 and 1865, some 250 ships suffered damage from lightning. Between 1793 and 1815, 100 line-of-battle ships and frigates had, either wholly or partially destroyed a large number of upper and lower spars or masts. Many ships lost stores, while one ship in eight caught fire. Some seventy seamen died and 133 were wounded. Forty-five ships were completely disabled and the total cost was estimated at £100,000. The record could never be complete however, since many ships went down after lightning strikes with no survivors to tell the tragedy.¹ In contrast to Cavallo's statement, it was later pointed out by William Sturgeon that marine lightning conductors (in the form of fixed wire conductors) were not generally fitted to ships before the turn of the 18th century. The losses recorded above become more comprehensible in the light of the following extract from Sturgeon's "Lectures on Electricity":-

"Marine lightning conductors are simply chains of copper, formed of links similar to those of the surveying chain. But the lightning has frequently struck ships before the chains could be got up; fixed conductors have been proposed and some are on trial with the Navy."²

We may presume that the truth of the matter lies between the two statements by Cavallo and Sturgeon. Clearly, fixed wire conductors were in use in the 1780s (it being unlikely that Cavallo would boldly state a falsity) but they did not entirely supersede chains, even at as late a date as the 1840s when Sturgeon wrote. Indeed, the serious study of the use of fixed copper conductors began with the work of the Birmingham inventor, Benjamin Cook, in 1811³ and as we are reminded by Sturgeon,

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- 1 Cyclopaedia of Useful Arts and Manufactures p. 555.
- 2 Sturgeon W. Lectures on Electricity. Gilbert and Piper 1842 p. 207.
See also William Watson's comments p. 134 on the disadvantages of chains as conductors.
- 3 Ibid p. 207. Cook was described as an "ingenious inventor" and a "well-known tube maker." His patents were numerous and his work is well documented in Prosser's Birmingham - Inventors -. (p. 47, 88, 91, 93, 96, 165, 166, 179, 185-7, 191) where Cook's interest in copper is made clear.

Cook was the originator of the idea "of carrying the conductor through the body of the ship".¹ In this case, as in many later instances, the conductors were either taken to large copper keel bolts in contact with the sea, or in the case of "copper-bottomed" vessels, to a bolt in contact with the copper sheathing. Eventually, mainly through the work of William Snow Harris, fixed conductors of rolled copper strip and copper strip laminate would be used² in preference to copper wire. But in such instances, the laminate would be plated into recesses in the masts by using "short copper nails".³ Whatever the form of fixed conductor however, be it wire or copper laminate, little extra effort was required (to supply either the wire for conductors and chains or indeed for the nails) from the large manufacturing effort both inside and out of the dockyards. Little additional manufacturing capacity was needed in a situation designed to roll large numbers of ships bolts and nails and sheathing, widely used from the 1780 s. Whereas it had cost £650 to sheath the Frigate "Alarm" in 1763⁴, it was estimated that the cost of protecting a first-rate ship from lightning was only £100; this some fifty years later and in the face of rapidly rising copper prices.⁵

When, in 1769, lightning conductors were affixed to St. Paul's Cathedral (to Benjamin Franklin's specification) the conductors had been made of iron, and after the building was struck by lightning in 1772, portions of one conductor were seen to become red hot.⁶ Whether or not this event prompted renewed or more vigorous investigations in an attempt to find a better material for conductors will

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- 1 Sturgeon W. op cit p. 207. There is some contradiction here between Sturgeon's statement above and the previous one concerning the general utilisation of fixed conductors but it is probably due to his contracting and over-simplifying the sequence of events. It should be mentioned also that changes in naval shipping were not necessarily reflected in ships of the mercantile marine.
- 2 Ibid. See also Cyclopaedia of Useful Arts and Manufactures p. 555.
- 3 Cyclopaedia of Useful Arts and Manufactures p. 556.
- 4 Navy Board Out Letters to the Admiralty A.D.M. 106/2195 dated 31st August, 1763.
- 5 Cyclopaedia of Useful Arts and Manufactures p. 556.
- 6 Webster-Smith B. 'Sixty Centuries of Copper. C.D.A. 1965 p. 65.

remain a mute point. As far as electrical science was concerned, iron had been a common material in experiments for the transmission of electrical charge and perhaps it was this which justified the use of iron as a lightning conductor. Copper was however, as available (in the form of wire, rod and chain) as iron, but it was not cheap and as familiar a material as iron. The American physicist, Joseph Henry (1797-1878), is credited with citing the example of lightning traversing stone and glass in a building, only to be conducted away by 6ft. of copper bell wire¹ and some metal guttering.² Examples abound also, of buildings having been protected to some degree through the agency of copper bolts, which though principally intended to tie walls together, acted also as lightning conductors.³ However, little was known of the electrical properties of either copper or iron. Nevertheless, only two years were to elapse, from the date of the alarming incident at St. Paul's Cathedral, before the first serious investigation, into the conductivity of various metals, was published.

THE EARLY TRIALS IN CONDUCTIVITY

Though Stephen Grey, a Charterhouse pensioner, had shown in 1720 that electro-static charge could be transmitted by silk over a distance,⁴ it was left to the architect, John Wood in 1726 to demonstrate that the "electric fluid" could be conveyed through metallic wires over even greater distances.⁵ Wood's discoveries were extended later in 1747 when the "electrician" William Watson (with some members of the Royal Society)⁶ began experiments to determine both

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- 1 This refers to part of the mechanical linkage for actuating a distant bell oftines used to call servants. Vide supra also for further reference to this p.169 reference 1 and p.170. See also the account of bell-wire conducting lightning in Sir William Thomson's . Collected Papers -. Macmillan 1872 p. 232-3.
- 2 Cyclopaedia of Useful Arts and Manufactures p. 552.
- 3 Ibid. p. 554.
- 4 Mottelay P. F. A Bibliographical History of Electricity and Magnetism. Charles Griffin, London, 1922 p. 153.
- 5 Ibid. p. 158 et seq.
- 6 The party included Folkes, Cavendish and other distinguished members of the Royal Society.

the velocity, and the distance, over which the electric fluid might be transmitted.¹ Similar experiments had been performed; Joseph Franz, in 1746 discharged a Leyden jar through 1,500ft. of iron wire,² and in 1742 Andreas Gordon had conveyed electricity through iron wire to a distance of approximately 750ft.³ In 1746, J. H. Winkler used extended metallic circuits for a telegraphic purpose.⁴ However, it was left to Watson to design an experiment in the hope of answering one specific enquiry which concerned itself not with the question as to whether metals conducted at all, but the rate and distance at which a given metallic circuit could conduct. A number of previous experiments were probably known to Watson, especially the work of Grey and Wood. That a variety of metals conducted electricity to a greater or lesser extent, would doubtless also be a fact with which Watson was well acquainted. Even brass wire was a material in common use, indeed, Von Kleist in 1745 used it in Leyden jars.⁵ Thus it would seem that at the time of Watson's experiments, the conductors used would be those which were both familiar and easily available. It is interesting to note, however, that between 1725 and 1729 Stephen Grey, like Wood, had employed thin brass wire in his own experiments and between June 1729 and August 1730 Grey, and his associate Granvill Wheeler, communicated electric charge over brass wire exceeding 800 feet in length.⁶ Watson, while apparently not concerned over the nature of the metal to be used for conductors, did make a clear distinction concerning the form the conductor

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- 1 Watson W. "-Experiments to discover whether the electric power - would be sensible at great distances; with an enquiry into the respective velocities of electricity and sound -" *Philosophical Transactions* No. 485 (1748) Vol. XLV p. 49.
- 2 Priestley J. *History and Present State of Electricity*. 4th Edition, London 1775 p. 70, 77.
- 3 *Ibid.*
- 4 Mottelay P. F. *op cit* p. 162.
- 5 Mottelay P. F. *op cit* p. 173.
- 6 Mottelay P. F. *op cit* p. 154.

should take:-

" - wires - are preferable to chains" - "as many experiments had shown that whether it were a small wire, or a thick iron bar, the electrical strokes communicated thereby were equally strong-"¹

Chains, according to Watson were a further nuisance, they had been tried but:-

"besides the difficulty of procuring chains of requisite length - junctures of the - chain, not being sufficiently close; caused the Electricity in its passage to snap and flash at junctures."²

Watson carried out a series of experiments between July 14th 1747 and August 5th 1748 culminating in the discharge of a leyden jar through 12,276ft. of iron wire.

Watson concluded that the velocity of discharge was, if not instantaneous, "altogether inappreciable".³

Though Watson had implied that apart from its physical form, any metallic conductor in a circuit was passive and acted merely as a conveyor of "electric fluid",⁴ this notion was soon to be doubted. The generally held belief that metallic conductors were experimentally inert began to be dispelled first by Franklin and subsequently by a number of his contemporaries. In 1749 Franklin, in a letter to Collinson wrote:-

"Electricity fuses metals - so does lightning. Lightning rends bad conductors when it strikes them; so does electricity when rendered sufficiently strong".⁵

Both the recognition of good and bad conductors, and the idea that large charges of electricity could affect metals was, though clearly stated by Franklin, something which may already have been known to those experienced in observing the effects of lightning. It was a point however, that had not been accounted for in metallic

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1 Phil. Trans. op cit (XLV 1748) p. 61.

2 Ibid.

3 Phil. Trans. XLV No. 489, 491. See also Mottelay op cit p. 176 - It should be noted the P.C.C. Lemonnier carried out similar experiments at Paris in 1746 over 12,789ft. of wire, but he failed to match Watson in the intent of his experiment, noting only that he could produce shocks at a distance.

4 Though it must be said that mention is made that the report of the discharge on the extended circuit was not so loud as before. - Phil. Trans. 1748 XLV p. 92.

5 Mottelay P. F. op cit p. 194.

circuits used in experiments on the transmission of electricity. In such cases the conductor was either plainly of no consequence, or it became hot or fused during the passage of an electrical discharge. The idea of intermediate levels of resistance to charge transfer had not been conceived.

The Italian astronomer and electrician G. B. Beccaria (1716-1781) appears to have been the first to account for both variations in the conductivity of conductors and limitations in the velocity of electricity in "good" and "bad" conductors. In Priestley's History - he is credited with experimenting with the resistance of wires finding that:- "metal was not a perfect conductor".¹ Beccaria experimented with a 500ft. length² of iron wire suspended in a large building. By the use of a pendulum (beating $\frac{1}{2}$ seconds) he measured how long the discharge from a Leyden jar took to move a ball of gilt paper suspended at the extreme end of the wire.³ The spark or movement caused in the experiment was measured as $\frac{1}{2}$ a second, much more than "instantaneous". The experiment did not however, distinguish between resistance to the velocity of electricity and (the modern understanding of) resistance: the loss of energy by the conversion of electricity into heat or other physical phenomena. This distinction was to be left to Ebenezer Kinnersley who, working in Philadelphia in 1761, demonstrated the heating effect in metals some ten years after Beccaria's work.⁴ In a letter to Benjamin Franklin in March of 1761, Kinnersley described how he simultaneously discharged a number of Leyden jars through a brass wire, some 24 inches long, which had been suspended with a one pound weight at its free end. The wire became red-hot and Kinnersley claimed that he had found "a new method of wire-drawing" since the wire became annealed and was found to be an inch longer than before. A bigger charge melted the wire, it

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1 Priestley J. History -. op cit p. 201.

2 This was the "Paris" foot (Ibid).

3 Priestley J. History -. op cit p. 201.

4 Mottelay P. F. op cit p. 222.

parting near the middle into two sections which, when both were measured, added up to a total length of 28 inches.¹ In proof of the wire becoming hot, as well as red, Kinnersley ignited gunpowder and tinder with it and then taking another piece of wire, twice as thick, he found he could not produce the same effect. Kinnersley concluded that as for electricity, a large quantity would pass through a thicker wire without producing any sensible heat but the same, passing through a thinner wire, and being confined to a narrow passage (the particles crowding together meeting with greater "resistance") would make it red hot and even melt it.² According to Kinnersley, lightning did not melt metal by "cold fusion" as formerly supposed, but, through restriction in conductors, for if electricity were to pass through a sword blade the point might become red hot whereas the thicker section would not.³

Such results, as those of Kinnersley, contributed greatly to the understanding of both the behaviour and properties of lightning and the necessary characteristic of any system of conductors that might be used as protection. In essence, metallic circuits did possess resistance and to conduct a given amount of electricity safely it was necessary to ensure that the conductor was thick enough to do so. Though Franklin was the first to know of Kinnersley's results, his system of lightning conductors was overloaded when St. Paul's was struck in 1772. These circumstances provoked a question: how big did the conductors have to be to by-pass safely the most violent lightning strike? Thus, the logical progression in any such question is to ask which metals might be better than others in conducting electricity. Franklin's conductors had been of iron four inches broad and half an inch thick;⁴ perhaps the limit to the capacity of lightning conductors was set not absolutely by their physical dimensions but by the metal from which they were made.

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- 1 Kinnersley E. "New Experiments in Electricity" Phil. Trans. 1763 Vol. LIII, Experiment 9, p. 86.
- 2 Ibid.
- 3 Phil. Trans. Vol. LIII (1763) Experiment 10, p. 87.
- 4 Mottelay P. F. op cit p. 232.

It is reasonable that a further progression in any such question is to ask which metals might be better than others in conducting electricity.

THE ASCENDANCY OF COPPER -
QUANTIFICATION AND ELECTRICAL CONDUCTORS.

After numerous experiments with wire, the instrument maker, John Cuthbertson, concluded in 1769 that "equal quantities of electricity in the form of a charge will cause equal lengths of the same (steel) wire to explode".¹ Following this, in 1774, William Henley a linen-draper and F.R.S.² carried out a series of trials which included (as his sixth experiment) the determination of the relative conducting powers of different metals.³ Henley placed standardised gauges of wire ("all drawn through the same hole, except the iron which was somewhat larger")⁴ on thick pasteboard upon which ruled lines, one inch apart, fixed equal portions of wire (by way of some weights) one on each side of the graduations.⁵ For various lengths of gold, brass, silvered copper, iron and silver, Henley found that one unit of charge melted four inches of gold, six inches of brass, eight inches of silvered copper and ten inches of iron and silver. In the light of these results, Henley found the metals to hold the following decreasing order as conductors:- gold, brass, silvered copper, silver and iron.⁶ In 1774, (but submitted a little before Henley's entry) Edward Nairne (1726-1806) an instrument maker⁷ communicated through Philosophical Transactions his experiments with various diameters and lengths of different wires. Connecting together long and

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1 Mottelay P. F. op cit p. 231.

2 Dictionary of National Biography Vol. 11 p. 421.

3 "I attempted to ascertain the conducting powers of different metals"
Henley W. "Some Experiments in Electricity" Phil. Trans. Vol. LXIV 1774
p. 389 et seq.

4 Ibid.

5 Ibid.

6 Ibid. Though Henley's methodical experimental approach provokes little criticism, the purity of his samples remains in question, as does the accurate measurement of the charge repeatedly applied to each wire. Mention may also be made of his failure to appreciate the different melting points of the various metals and his failure to standardise the samples completely. Whatever the deficiencies however, it was non-the-less a beginning.

7 Dictionary of National Biography - Vol. 16, p. 25 "optical mathematical instrument maker". See also Philosophical Transactions 1774 Vol. LXIV p. 79 "London mathematical instrument maker".

short lengths of thicker and lesser diameters of iron, silver and platina wire, Nairne concluded that the longer lengths of fine wire offered "great resistance" to the "electrical fire".¹ Nairne, along with Priestley, would later be the first to maintain the superiority of copper over iron as an electrical conductor.

Though unpublished, a series of beautiful experiments to establish relative conductivities was carried out by Henry Cavendish (1731-1810) between 1771 and 1776.² There is however, good reason to suppose that much of Cavendish's results did become known and would have been generally accepted. In the Philosophical Transactions for 1776³ Cavendish wrote of "An - attempt to imitate the effects of the torpedo" in which he boldly stated that "Iron wire conducts 400,000,000 times better than rain or distilled water".⁴ Though later promising to publish the experiments leading up to this conclusion, ultimately he did not. It was said however, that "- such was the reputation of Cavendish for scientific accuracy that these bare statements seemed to have been accepted at once".⁵ Cavendish was acquainted with Nairne, Priestley and many others. It would seem unlikely that he ever failed to disclose what he considered to be an experimentally established fact, and there is much to suppose that he influenced a great deal of other work in ascertaining conductivities in various materials.⁶ His own experiments are now known, and many were designed to establish relative conductivities and to determine those factors which influenced and affected the phenomena. Cavendish utilised many

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- 1 Nairne E. "Electrical Experiments" Phil. Trans. LXIV 1774 p. 80-81.
- 2 J. Clerk-Maxwell (Editor). The Electrical Researches of the Honourable Henry Cavendish. Cambridge 1879 p. XLI.
- 3 Cavendish H. Phil. Trans. LXVI 1776 Part 1, pp. 196-225.
- 4 Ibid. p. 197.
- 5 Researches op cit p. LVI.
- 6 Ibid. p. XXXVII - It is true however, that he lived a comparatively secluded life. See also Researches p. LXIV - Cavendish also made experiments with Nairne and for this see Experiment 580 p. 297 of Cavendish's Researches. The fact that Cavendish and Nairne carried out experiments together and that Nairne and Priestley co-operated in experiments tends to deny the argument that Cavendish would have failed to influence the other two in their experimental work.

types of wire in his experiments: iron;¹ brass;² copper and also silvered copper wire. Cavendish compared the conducting power of iron wire and salt water, by estimating the shock he received from the discharge of a Leyden jar which could choose to pass with proportional intensity through two circuits, consisting of the iron wire and the salt solution, or his body.³ As for copper wire, Cavendish carried out at least one very important experiment (No. 636),⁴ which compared copper wire against a salt solution, and a number of other materials. The experimental method was basically the same but accounted for silvered copper wire,⁵ and also whether or not a copper conductor which had "many knots in the wire"⁶ might have a bearing on the results. He noted that the shock received through 166 inches of copper wire "without any knots in it" was the same as if received through a piece of wire of the same length with "37 knots in it".⁷ In some of the experiments, copper wire was stretched some 14 times around the garden⁸ of the laboratory at Great Malborough Street.⁹ The length of copper wire was about 500 yards.¹⁰ In all his experiments with copper wire, Cavendish employed lengths ranging from that which stretched some 840 yards and weighed one grain for every 9.24 inches,¹¹ to samples which were 823 yards in length and extended 9.984 inches to the grain.¹² Of silvered copper wire, he utilised almost

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1 Researches op cit p. 219.

2 Ibid. p. 222, 295.

3 Ibid. Experiment 576 p. 294 - This of course was the basis for Cavendish's statement on comparative conductivities in the "Torpedo" report in the Phil. Trans. for 1776.

4 Ibid. "Comparison of resistance of copper wire with that of salt solution" p. 338.

5 Ibid. Experiment 644 p. 342. This was probably Sheffield plated wire.

6 Ibid. Experiment 636 p. 339.

7 Ibid. Experiment 640 p. 340.

8 Ibid. Experiment 643 p. 341.

9 Ibid. p. XXIX.

10 Ibid. Experiment 641 p. 340.

11 Ibid. 30220 inches - see Experiment 641 p. 340.

12 Ibid. 29623 inches - see Experiment 636 p. 339.

a mile which for every 10.93 inches weighed one grain.¹ In each case the experiments relied upon remarkably fine wire. A small sample of the wire used by Cavendish was made available to the author, and although the subject is examined more closely later in this work,² it is for the moment sufficient to say only that the specimen was shown, after tests, to be almost pure copper. The gauge appeared to be (due to its corroded appearance) approximately 23 B.W.G. (1890) and on this basis, Cavendish was dealing with resistances of the order of 146 ohms for a length of 840 yards. According to James Clerk-Maxwell, Cavendish would have experienced resistances of between 424 ohms (annealed) and 433 ohms (hard drawn) for the 823 yards of 9.984 inches per grain wire, and between 984 and 1,004 ohms for the silvered copper wire of 10.93 inches per grain.³ The disparity is not significant since the sample made available to the author, although of established provenance, is simply a specimen not mentioned by Cavendish as having been used in his experiments. The wire that was used appears to have been all No. 7 B.W.G. (.185 inches)⁴ contrasting with the No. 23 B.W.G. (.025 inches) of the author's specimen. It is note-worthy that Cavendish was able to obtain very long lengths of copper wire. He mentions no joints - only knots.⁵ The most suprising item however, is the purity of the author's specimen. If this was typical of the quality of Cavendish's wire, then it could only have been due to chance - all other evidence points to extremely variable levels of purity (and conductivity) for copper wire in Cavendish's era (the same being true up to the 1850 s).

Both Henley and Cavendish used silvered copper wire in their experiments

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- 1 Researches - 62790 inches, Experiment 644 p. 342.
- 2 Vide supra appendix 1 p.171 et seq.
- 3 Researches p. 343 - The author repeated the calculations and they compare well with Maxwell's.
- 4 Cavendish clearly attempted to standardise the dimensions of his wire - Maxwell notes that wire lengths of 72 inches (and multiples) were favoured. This supports the idea of Cavendish utilising a standard wire gauge. See Researches p. L.
- 5 Researches p. 339.

and some brief comment on this might be made here. However, what is said must be confined to the observation that it would seem possible that the silvered wire was the product of the plate maker, gold smith or silver smith but more likely it originated from the Birmingham or Sheffield plate makers. Such a fine gauge would, generally, be more in keeping with the filligree work usually found in the silver smiths craft. Nevertheless, silvered copper wire was more commonly found as a product of the plate maker.¹

Silvered copper wire was also considered by Nairne and Priestley when in 1780 they conducted a series of experiments² which bore some relation to those of Kinnersley in 1763.³ Nairne investigated the contraction of fine wires due to their being made red hot by the passage of an electrical discharge from batteries of Leyden jars. Both iron wire and "copper wire, gilt with silver",⁴ of the same dimension (ten inches long and 1/100th of an inch in diameter)⁵ was tried and Nairne concluded that the copper wire conducted better than the iron.⁶ Though Nairne appears to have been the first to publish the experimental basis for the belief that copper conducted better than iron, a list of conductors placing copper after gold and silver (but before platina, brass and iron), had been published by Cavallo in 1777.⁷ The value of this list, and the extent of its acceptance, may be gauged by the fact that as late as 1807 Thomas Young⁸ reprinted Cavallo's table (with acknowledgement as to its source) and even in 1842 it was to be seen in Sturgeon's Lectures.⁹ Sturgeon however, supplemented Cavallo's list by giving a table of conductors taken from Cumming's Manual of Electro-Dynamics placing

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- 1 Vide infra Ch.4 P. 107. et seq.
- 2 Nairne E. "On the Effect of Electricity in Shortening Wires". Phil. Trans. LXX 1780 p. 334.
- 3 Whereas Kinnersley had weighted wires and drawn them out when they heated due to an electrical discharge, Nairne and Priestley allowed the wire to hang slack, consequently noting some contraction.
- 4 Phil. Trans. LXX op cit p. 337.
- 5 Ibid. p. 334.
- 6 Ibid. p. 337.
- 7 Cavallo T. A Complete Treatise of Electricity -. op cit p. 8.
- 8 Young T. A Course of Lectures on Natural Philosophy and the Mechanical Arts. 2 Vols. J. Johnson London 1806 Vol. 2 p. 421.
- 9 Sturgeon W. Lectures op cit p. 12.

copper second after silver, with lead, gold, brass, zinc, tin, platina, palladium and iron following in descending order.¹

It remained generally true however, that copper gained only a grudging acceptance as a first class conductor and it competed simultaneously with iron, brass and gilt copper. It was the latter which was proposed by Linguet (the French advocate) as a conductor in a telegraphic system suggested in 1782.² This example was exceptional and few, if any, declarations of preference were made by any experimentalists working in electrical science at this time. The choice of conductor was invariably arbitrary, and it is easy to conclude that although copper might have been acknowledged as technically a superior conductor, it was still felt that almost any metallic conductor would do; provided that it was low in cost and easily available in reasonably long lengths. Conductors of iron and brass as well as copper are found indiscriminately in the experiments of the time. (Lomond, for example, used brass wire in a successful one-wire telegraph system set up in 1786).³ The lack of emphasis on the choice of conductor is perhaps a result of a decision not to place too high a priority on the quality of the conductor. Only in the case of lightning conductors was a preference for one metal, as opposed to another, either important, or in evidence. Whereas in the electrical science of the 18th century the Leyden jar (capable of delivering a high voltage discharge for a relatively short period of time) was the common method for accumulating electric charge, its high voltage discharge seldom incurred much loss over even considerable lengths of conductor whatever the type of metal.⁴ In lightning conductors both extreme electrical potentials and large currents were experienced and in this case the small difference between the conductivity of various metals became significant. The resistance of a conductor was accountable when high currents were likely either for extended periods of time, or when the current flow was of such a magnitude as to produce instantaneous overload. Metals with a positive temperature

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1 Ibid. p. 13.

2 Mottelay P. F. op cit p. 265.

3 Ibid. p. 286.

4 See Mottelay P. F. op cit p. 286 who quotes Young - "-the length of brass wire makes no difference in the effect".

coefficient increase in resistance when hot, and generation of heat in a resistive conductor is a direct function of the electric current (I^2R). Since the Leyden jar, even in large series parallel networks, was unable to deliver large quantities of current for long periods of time, the problem as outlined above was merely transitory. This consequence of the physical effect of short duration discharges upon wires, affected electrical science in the period in which the Leyden jar was technologically necessary. It was the existence of the Leyden jar (which besides the electro-static generator, was the only other convenient source of electric charge) which both indicated the existence of a disparity in the conduction properties of different metals, and at the same time, the evidence that the disparity was of little consequence. Though electric current was later to become important, at this time it had not been clearly identified and its effects were not understood. While, however, electric current remained poorly understood, the idea of potential difference was better conceived but this neither was to be well appreciated until the advent of the Voltaic piles and the work leading up to that of Ohm. The new electrical science based on current electricity superseded the fruitful fifty years of electro-statics, resulting from the Leyden jar, which had preceded it. Volta, in 1796, constructed his successful battery "Le Couronne de Tasses" (Crown of Cups) following investigations into dissimilar metals.¹ Volta's inspiration had come from Galvani's observations of movement in frogs legs through the agency of a copper hook and an iron nail.² It is interesting that both copper and iron should have played such a role since both metals would later vie for dominance as conductors in the new age of current electricity, telegraphy and telephony. Indeed, it is probable that Galvani's copper hook was fashioned from rod formed in an entirely similar manner to common copper wire. Once again demonstrating the versatility of copper rod and wire, and a further example of its utilisation.

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1 Mottelay P. F. op cit p. 247 and Britannica 13th Ed. op cit Vol. II p. 242.

2 Ibid.

CHAPTER 6

CONDUCTION, COMMUNICATION & COMMERCE

1800 - 1830

As regards copper in the wire industry, the 18th century left as a legacy both a good industrial platform (where manufacturing techniques were advancing) and established markets, both traditional and newly developing. Not all was gain however. Though many companies had either survived or perpetrated monopolistic practices,¹ and had consolidated their positions in the face of

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- 1 Some companies might be said to have been forced into existence. The principal example of this being that of the Birmingham Mining and Copper Company (formed August 1790) and the Birmingham Metal Company (formed November 1780) who along with the Rose Copper Company (1796) came into existence to ward off price fixing on brass and copper by combines such as the Bristol and Cheadle Co's. (See Hamilton op cit pp. 204, 218, 226, 234-6). The year 1790-1 had proved to be boom years for the copper industry, contrasting with the slump of 1793 following the panic over the impending war against France in that year. 1792, as with 1790 and 1791, had seen an increased demand for the copper sheathing of ships with a consequent increase in the production of rod and wire for bolts and nails. The depression of 1793 was followed by a revival in the fortunes of the copper industry but the market changes and the demands of war had resulted in high copper prices (Hamilton op cit p. 205-209, the higher prices being paid by the Government dockyards). The copper trades in Birmingham and Wolverhampton lost their French and Italian export markets almost overnight, and with export and import restrictions the copper wire industry along with those trades utilising wire felt a severe depression. Interruption in the export markets to Germany and Spain also depleted the resources of the copper trade and little could be done to remedy it. Birmingham had felt the ravages of monopoly and price fixing by copper suppliers since the 1780s which resulted in remedial acts such as the forming of the Birmingham Metal Company (Joint Traders in the Art and Mystery of Making and Selling Brass, Spelter and Other Metals - see Day J. op cit p. 106). A mining and smelting company was established by April of 1790 (Langford J. A. A Century of Birmingham Life. Birmingham 1868 Vol. I p. 348) and to some degree this restored confidence in the Birmingham trades. The advent of war however, was another blow. Of this period, it was said "Everything paid duty - everything was taxed from the light of heaven to the powder on the hair - Nothing escaped the lynx eyed Chancellor of the Exchequer and the terrible French War had stomach for it all". (Langford op cit Vol. I p. 355).

The fear that potential enemy ships might be improved by British copper sheet maintained duties on bolts, nails and sheets for sheathing, thus discouraging export. Even if it could be made, the article of copper was to be expensive, and copper wire and copper rod rode the same price wave as other copper commodities. There was some room for optimism however, free enterprise was still in evidence in the appearance of new companies and new techniques in manufacture.

erratic copper markets, many had gone to the wall. One notable example is that of the Bristol Mills at Lewis Mead owned by John Champion Junior, the last of the Champion family¹ to involve himself with the brass, copper and wire industry. Champion's Lewis Mead Mills at Bristol were put up for sale in January of 1799.² In the previous year, describing himself as a "Manufacturer of brass, copper and iron wire", Champion had taken out a patent for improvements in making iron wire.³ The benefit of this patent to John Champion seems to have been little, and nothing is known of him after 1807.⁴

To balance this loss, the period saw also the formation of Johnson & Brothers (circa 1789) a company which, on becoming Johnson & Nephew (1877) would stand as an important concern in the late 19th century copper wire industry, due in part to its connection with G. Bedson, of which more is said later in this work.⁵ Whereas industry, apart from its internal conflicts, could face export restrictions, tariffs, taxes, booms and slumps, it appeared totally unprepared for a new future which from the middle of the 19th century would transform it. The 18th century began to place a new emphasis upon the utility of experimental science, and one application, exploiting the constantly repeated proposals for electric telegraph systems, both signposted the new direction for the wire industry and resulted in many experiments to demonstrate its potential. The transmission of electricity over long-distance metallic conductors had already been proven. Such experiments, along with those which examined the electrical properties of metals indicated a new direction soon to be taken by the (copper) wire industry. The path however, needed to be cleared through further experiments by the new breed of scientist/technologist who, in company with other innovators and inventors (both within and outside the wire industry), were to consume the new electrical discoveries

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- 1 Day J. op cit p. 127-129 - see also Raistrick A. op cit p. 198-200 also Ch. 3 p. 101-102
- 2 Day J. op cit p. 128.
- 3 B.P. No. 2239 filed 18th June 1798, granted 21st June 1798.
- 4 See Raistrick op cit p. 200 and Day op cit p. 129 who quotes the apparently unconnected bankruptcy of one J. Champion in 1811.
- 5 See Ch. 11 p. 231.

in every practical way. The tremendous advances made in only a few short years after 1800 by Volta, Nicholson, Carlisle, Cruikshanks and Babington¹ in improving the Voltaic pile were to alter the state of electrical science and the role and importance of copper wire. Though the wire industry was to see a greater emphasis on copper wire in the first thirty-five years of the 19th century, the manufacture of copper wire for the traditional industries prevailed, and this remained the corner stone and basis for the supply of copper wire for electrical science. But though the traditional industries had made copper rod and wire a familiar and available material, the engineering difficulties encountered in the implementation of a practical telegraphic system were due to inexperience of the wire industry in the drawing of long lengths of wire, and the hitherto undiscovered problems which were to surround the electrical and mechanical deficiencies in traditionally made copper wire. It can be said that even today not every difficulty encountered in the utilisation of copper wire in communication and power transmission has been solved. However, it counts for much that even as early as 1860 the majority of the difficulties in using copper conductors in mechanically extreme, and environmentally hostile situations had been solved. Every solution of any of its deficiencies as a conductor made the future of copper wire more sure and lessened the influence of the traditional industries in the manufacture (and the constraints in manufacture) of copper rod and wire. As the need for copper wire increased, so industrial expansion and new methods of production in the wire industry became necessary, if not crucial. The issue was fundamentally one about the question of how fast the capacity of the wire industry could expand, and how quickly could new applications utilise the increased capacity. The converse, of course, was also true; depending on the consumption of wire through new applications, the production of copper wire might be expected to adjust accordingly. It would be reasonable to suppose that the electrical application of copper

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1 Mottelay M. op cit p. 247, 335-338.

wire in the early 19th century was all the greater for the discovery of current electricity. It seems however, that the role of copper wire in this respect was limited. Consequently, although for the first twenty years of the 19th century it was much more used,¹ it was not to markedly effect the wire industry. The early years of the 19th century appear as transition years, copper wire being utilised in what would be regarded as very small amounts when compared to consumption some forty years later. The trials, tests and experiments of the first three decades of the 19th century were necessary to establish the electrical techniques and principals which were to make copper wire the basis of electrical technology and electrical engineering. These were years which were necessary for the wire industry to gain an appreciation of a potentially large market and expand. What expansion did take place, however, is not to be attributed entirely to the demand for copper wire in electrical and traditional applications. Iron wire, too, finding a new role in telegraphs, contributed greatly to the expansion of the wire mills. Both copper and iron were to be subject to fashion as well as engineering criterion.

The beginning of the 19th century can be thought of as not distinctly different from the late 18th century as regards the experimental work in conduction and other aspects of electrical science. Monumental discoveries had occurred it is true, but no abrupt change took place in the overall level of work carried out in classifying electrical conductors. In examining this area of science, history presents a slow but significant improvement during the period, in both the exactness in experimental methods and the understanding of the properties of metallic conductors. A newly developing rigour in experimental method and the ability to utilise the Voltaic pile, enabled much more to be done in establishing the properties of the various components in an electrical circuit. The culmination of all this work is to be found in the endeavours of G. S. Ohm and M. Faraday. But in citing important examples of such work before the time of Ohm and Faraday, it should be noted that events quoted as outstanding contributions in the history of copper wire may, in their time, have been

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1 Vide supra Ch. 8 p. 194.

of limited importance; sometimes serving only to confirm earlier work. Indeed, some work was to be regarded (and treated) as a curiosity, but in retrospect may be seen (not unexpectedly), as the precursor of later important events. Much of the work worthy of mention in these early years was carried out at the Royal Institution, a centre of 19th century experimental science, and the possessor in its early years of some of the most powerful batteries of the time.

CONDUCTORS AND CONDUCTION

In 1813, J. G. Children (1777 - 1852) constructed a battery on a plan suggested by W. H. Wollaston (1766 - 1828).¹ This huge electric source consisted of twenty-two plates making up twenty-one cells - each containing two copper plates and one of zinc, all six foot long by 2ft. 8ins. wide.² The combined capacities of each cell amounted to 945 gallons.³ Children determined to test the "comparative facility with which different metals are heated when placed in the electric circuit"⁴ and using wires of platina, iron, copper, gold, zinc and silver (all eight inches long and 1/20 inch diameter) found that the conducting power of the metals tried was as follows:- silver, zinc, copper, iron and platina. It may be suggested that Children's sample of copper was typical for the period and does not speak well of the purity of copper wire available at this time.⁵ Children mentions the constant attendance of W. H. Wollaston during his experiments and at one point employed a fine wire of platina (1/5000 inch in diameter and 1/30 inch long) which had been supplied by Wollaston. The wire was the result of Wollaston perfecting a technique able to produce very fine wire, at times almost imperceptible to the naked eye. Amongst Wollaston's achievements in producing apparatus for "popular uses"⁶ was a thimble battery, and his ultimate achievement in this respect was the manufacture of fine wire to compliment it. Wollaston's endeavours in working apparatus on a reduced scale,

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- 1 Children J. G. "An Account of some Experiments with a large Voltaic Battery" Phil. Trans. Vol. 105 Part 2 (1815) p. 363.
- 2 Ibid.
- 3 Ibid. p. 364.
- 4 Ibid.
- 5 Conductivity improving as a function of the copper purity and its mechanical condition.
- 6 Mottelay P. F. op cit p. 358.

his interest in utility (coupled with a "genius of fingertips")¹ was embodied in a mechano-chemical method of wire making. Wollaston described his method (only months before Children's paper was read before the Royal Society) in the Philosophical Transactions for 1813.² By taking a pre-drawn gold or platinum wire, and coating it thickly with silver, he showed that by further drawing the now comparatively thick rod once again, and reducing it to its former diameter (1/100th inch) he could, on dissolving away the silver with nitric acid, produce an extremely fine gold or platinum filament.³ Some other methods of producing the same result consisted of drilling a hole through the centre of a silver rod and inserting a gold or platinum wire, or casting a silver rod around a gold or platinum wire. In both cases the resultant composite would be drawn down and the silver dissolved away; this left a very fine wire.⁴ Wollaston achieved diameters for fine platinum wires in the order of 1/30,000 inch⁵ but these were formed by way of his first method - the alternatives presenting various problems. Wollaston's method was not however entirely novel, having its origins in techniques known well before his time.⁶ This does not detract from the success or value of

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- 1 Dictionary of National Biography Vol. 25 p. 315 (after Halsted).
- 2 Wollaston W. H. "On a Method of Drawing Extremely Fine Wires". Phil. Trans. 1813 Part 1 p. 114-118.
- 3 Ibid. p. 114-115.
- 4 Ibid. p. 116-117.
- 5 Ibid. p. 117.
- 6 Wollaston, himself, refers to Musschenbroek for an example of gold wire, recorded as having been drawn by a wire-drawer of Augsburg, so fine as to have a length of 500ft. per grain weight (Phil. Trans. 1813 Part 1 p. 114). Of greater significance is the extract from Power "- and your wire-drawers know that if they take a short piece of wire as thick as a quill and drill it through, that though they draw it out to the smallness of a hair, yet will it still remain hollow quite through in despite of their Wurdle", (draw-plate). (Power H. Experimental Philosophy Martin & Allestry - London 1664 p. 56). Beckmann describes a similar operation to that perfected by Wollaston in his History- (1780-1805) "The comparison of an idea abstracted from matter will appear the more ingenious when it is known that the finest gilt silver wire, when put into pure aqua-fortis, looses the silver in the inside so that nothing remains but a small and exceedingly thin tube of gold. I have frequently made this experiment but it succeeded only sometimes; and is one proof of the almost infinite divisibility of gold -" (Beckmann J. History of Inventions and Discoveries J. Walker 1814 Vol. IV p. 579). See also, for mention of similar techniques, article "Wire" - Cyclopaedia of Arts and Sciences" 2 Vols. - London 1738 (B.M. 715.1.23).

Wollaston's work - his knowledge and resourcefulness allowed him to contribute a technique which was to prove very valuable to science in general and to optics in particular. Wollaston's family was to be further involved with the subject of wire in later years when C. J. Wollaston, W. H. Wollaston's nephew, was to act as engineer to the Brett brothers, in which capacity he took the honour of being the first to order a copper wire conductor for a submarine telegraph intended to establish communication between England and the Continent.

Fine platinum wire was a feature also of the experiments carried out in 1821 by Humphrey Davy (1778-1829). In a report given in the Philosophical Transactions for 1821¹ Davy remarks on the ability of a six inch platinum wire (1/220th inch in diameter) to discharge ten double plates of a battery, while half the length (three inches) discharged twice as many (20) and yet half the length again (one and a half inches) twice the previous number of plates (40).² Since, as Davy says, it "occurred to me that the conducting powers of different metals might be more easily compared in this way -" he proceeded to determine the relative conductivities of platinum, silver, copper, gold, lead, palladium and iron. His results indicated that silver had the highest conductivity followed by copper, gold, lead, platinum, palladium and iron.³ Referring to Children's experiments,⁴ Davy takes the notion of heat production in a conductor as a function of its resistance (" -that the heat is in some inverse ratio to the conducting power")⁵ and considers conduction from the point of view of heat generation. By making use of the heating effect in wires of different metals (and thereby utilising the concept of resistance rather than conductivity) Davy found that his specimen of iron had the highest resistance (evolving the most heat under standard conditions) while silver heated least of all. With this method Davy found relative conductivities in the order:- silver, copper, lead, gold, zinc, tin, platinum, palladium and iron. Four years after Davy had published these results, A. C. Becquerel

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1 Davy H. "Further Researches on the Magnetic Phenomena Produced by Electricity -" Phil. Trans. Vol. CXI, 1821 pp. 425-439.

2 Ibid. p. 433.

3 Ibid.

4 Ibid. p. 438, 439.

5 Ibid.

(1788-1878) published his table of relative conductivities for various metals.¹

Though frequently referring to Davy's 1821 paper, Becquerel's work strode ahead and by means of the first differential galvanometer, he was able to form a table of metallic conductors relative to copper. For the first time the performance of metals as conductors could be compared quantitatively with a high degree of confidence,^{*} and it is remarkable that Becquerel's results could appear some two years before a true mathematical theory of the electric circuit; as expounded by G. S. Ohm in 1826-7.² To arrive at his table, Becquerel employed a circuit which allowed him to determine, by direct experiment, that the current in a series circuit is the same in all parts.³ This fact alone was essentially a statement which both preceded a vital part of Ohm's Law, and, once established, enabled him to evaluate the conductivities of metals. Utilising what he called "red copper"⁴ Becquerel assigned it the value 100 as a conductor, and compared other metallic specimens to it. His table is found with gold designated 93.6, silver 73.6, zinc 28.5, tin 15.5, platinum 16.4, iron 15.8, lead 8.5, mercury 3.45 and potassium 1.33.⁵ From this it may be concluded that Becquerel's copper was either exceedingly pure or his specimens of silver and gold were heavily contaminated with impurities, consequently reducing their conductivity. Since there is much evidence to indicate that copper for this period left much to be desired as regards purity,⁶ it would at first seem that the first argument cannot stand. It is curious however, that Becquerel talks of "red" copper, and not just of copper. On this basis it must be concluded that he had established a source for a fairly pure

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- 1 Becquerel A. C. "De Pouvoir Conducteur de L'Electricite dans le Metaux -" Annales de Chimie et de Physique Vol. XXXII (second series) 1826 p. 420-430.
 - 2 Shedd J. C. "The History of Ohm's Law" Popular Science Monthly Vol. 83 (1913) p. 604.
 - 3 Ibid. p. 605.
 - 4 Becquerel A. C. op cit p. 428.
 - 5 Ibid.
 - 6 Vide Chapter 1 - and also the estimated values for early submarine telegraph conductors etc., Ch. 7 p. 172.
- * Though previous experimenters (Nairne, Henley, Cavendish etc.) had carried out experiments designed to produce quantitative results, because of various deficiencies in method and apparatus the outcome remained inconclusive.

copper with high conductivity. (The redness of the copper indicating perhaps an annealing process which tends to improve conductivity in itself).¹ In addition to this, the comparative conductivities of the silver and gold are indicative of a low purity silver resulting in an upgrading of the positions of gold and copper. Indeed, it is noteworthy how selective Becquerel was in his choice of copper. Had he not been so, then the value of his work would have been that much the less. The excellence of his results are reflected in the way his work was acclaimed (through being frequently quoted in later papers).² The overall value of Becquerel's work is, however, difficult to estimate. This is especially so in terms of later investigations into comparative conductivities which tended to reverse the order of some of the metals in Becquerel's table. It was Becquerel's method, one of high scientific integrity, which precluded any questions as to the validity of his results. In terms of establishing a method for evaluating conductivities, it was a true advance. Copper was promoted to the position of first choice as an electrical conductor and the authority of Becquerel consolidated the position. Ultimately, however, the fact remains that Becquerel's table was accurate only for his particular specimens of metal. Becquerel's scientific method masked the fact that, for this time at least, no two samples of wire were alike since little consideration was given to achieving an understanding of the effects of impurities upon the conductivities of what were thought to be pure metals. The rigour of Becquerel's techniques are equal in standing in many ways to the experimental expertise of Faraday. However, it seems that Faraday took little note of Becquerel's work in the material sense since there is no indication that the copper wire used by Faraday was in any way selected for its conductivity. There appears to be no difference in the range of

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- 1 See Ch. 7 p.185 for Matthiessen's results of conductivities between annealed and hard drawn copper.
- 2 Fleming Jenkin "Report of the New Unit of Electrical Resistance -" Reports of the Committee on Electrical Standards - British Association for the Advancement of Science, E. & F. N. Spon, London 1873 p. 191. See also Shaffner T. P. The Telegraph Manual. London 1859 p. 33 - vide supra also Ch. 7 p.188 which refers to E. Becquerel's reference to his father's work and W. H. Preece's 1860 paper on "Submarine Cables" which quotes Becquerel (with error) - see Proc. Inst. Civ. Engs., Vol. XX (1860-61) p. 38.

conductivities in the wire used by Faraday after 1826 as compared to that used before this time.¹ Had Becquerel's work been any influence upon Faraday then it might be expected that following Becquerel's 1826 paper, efforts would have been made to select wire equal to Becquerel's standard. This does not appear to be the case, however. Since there is no evidence to indicate otherwise,² it must be assumed that Faraday made no effort to be selective in the wire he used,³ and the copper wire provided by Mr. Newman (Instrument Maker to the Royal Institution) appears to have been erratic in quality and indifferent in its range of conductivities. Perhaps there is truth in the argument that the effort and difficulties likely to be experienced at this time to maintain a standard in copper wire equal to that of Becquerel's, may well have out-weighed the advantages. This would have been particularly so as regards the kind of experiment being carried out by Faraday during the period 1821-1831. This point however, is more fully discussed in Appendix 2.

CONDUCTORS FOR EARLY 19TH CENTURY EXPERIMENTAL WORK

Supplies of copper wire for early 19th century electrical experimental work (including that on telegraphy) appeared to rely heavily on traditional sources both for the wire itself and for the means of producing electrical insulation. As late as 1830, Joseph Henry (1797-1878) mentions the use of "540ft of copper Bell-wire wound in nine coils of 60ft each -"⁴ in his experiments on electro-magnets. From this we may conclude that the copper wire used by Henry was the same as that incorporated into the mechanical system of pulleys, links and pivots used to operate

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- 1 Vide Chapter 1..
- 2 Personal communication with Professor R. King at the Royal Institution - December 1976.
- 3 As late as 1831 Faraday employed iron wire in his experimental work and at this date some of the copper wire in use had conductivity as low as 38% of the 1913 International Annealed Copper Standard. Vide Appendix 2.
- 4 Silliman. American Journal of Science. No. 19, January 1831 p. 403 - to be found in Fahie J. J. A History of Electric Telegraphy to 1837. London 1884 p. 291.

remote bells in the servants quarters of great houses.¹ Though Henry is also credited with being the first to adopt silk-covered insulated wire² this method too owes its origin to a traditional industry. We are told by Thomson:-

"- the Philosophical Instrument makers took advantage of the silk-covered wire of the milliners; only using instead of the iron wire which had served their purpose, copper wire as being five or six times as good a conductor of electricity."³

No. 14 B.W.G. copper wire was available to the experimenter mainly as Bell-wire selling in 60 yard lengths at approximately 1s. 6d. a pound.⁴ This, however, if requiring insulation, would go either to the instrument maker or to the opticians who also had methods of covering wire (as used in binding the wire found in the bridges and arms of spectacles). The opticians did not appeal to economy however. Their prices were described as "enormous"⁵ and many experimenters ignored both the opticians and the instrument makers, reverting instead to the originators of the covering method - the milliners. The milliners charged 6d. a pound to cover the copper wire as they would "bonnet wire" and this was one third the amount that was charged by the opticians for the same service.⁶ 2½lbs of copper wire would be covered for 2s. 6d. in 1837; No. 16 gauge copper wire was available at 1s. 3d. per pound.⁷ Covering the wire with cotton, rather than silk, worked out at 4d. per pound less.⁸ For the individual experimenter then, a number of options were

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1 Vide infra Ch. 4 p. 121.

2 Encyclopaedia Britannica 13th Ed., 1926 Vol. 13, p. 299.

3 Thomson W. "The Atlantic Telegraph" The Good Words January 1867 p. 46.

4 Mechanics Magazine No. 717, 1837 p. 319 - No. 14 B.W.G. weighed about 4lbs for a 60 yard hank (coil).

5 Francis G. "Insulated Wire" Annals of Electricity, 2, 1838 p. 396.

6 Ibid.

7 Ibid.

8 Ibid.

available. Insulation (cotton or silk) was available from three sources, while a reasonable variety of copper wire gauges based on traditional applications might be had. Though Bell-wire, and the traditions that surrounded its original application was in evidence even as late as the first decade of submarine-telegraphy, finer gauges of copper wire were favoured when available. Between 1820 and 1832 for example, Faraday utilised some seven different gauges of wire ranging through 8, 12, 17, 18, 19, 20 and 24 B.W.G. (1889).¹ Some surviving examples of Faraday's wire still exhibit cotton-wound insulation typical for the period. By 1837, it was possible to construct for oneself a machine for insulating copper wire on a plan devised by W. Ettrick. Ettrick's need to cover considerable quantities of copper wire with "thread" resulted in his designing a machine with this purpose in mind, and the description of it was published in 1837 (2 years after its invention)² and by use of the machine, 400ft. of wire per hour could be insulated.³

In the same year as Ettrick conceived the idea for his machine (1835), a patent describing apparatus with a similar purpose was taken out by J. P. Westhead of Manchester.⁴ Though of a more universal nature (Westhead's machine was contrived for "wire, cord, gut, thread" or other substances)⁵ it was never to have the same importance as the insulating machines of Ettrick or the artificer Henry Mapple. Mapple was later to be connected with Charles Wheatstone and this was to enhance the fame of Mapple and his machinery in the context of being one of the first suppliers of insulated submarine-telegraph cable.⁶

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1 Vide infra Ch. 1.

2 Mechanics Magazine Vol. 27, No. 717 (Sat. May 6th 1837) p. 66.

3 Ibid. p. 67.

4 British Patent No. 6896 dated March 1836.

5 Ibid. p. 1.

6 Vide supra Ch. 7 p. 166.

COPPER WIRE - 19TH CENTURY TELEGRAPHS

Though the history of the electric telegraph abounds with examples of the utility of copper wire, it is not however, a chronology of events concerned with the ever progressive and ever increasing dominance of copper as a conductor. That copper, in the form of wire, was incorporated more and more into experimental telegraphs from the beginning of the 19th century may be seen as a consequence of the belief that the advantages of copper as a long distance conductor¹ were well understood. However, without the experience of its electrical, but more importantly its mechanical deficiencies, it was to be a costly presupposition. The early years for experimentation were needed to prove telegraphic techniques, and to provide the lessons of practical installations subject to hostile conditions, and the demands of economy. In the beginning however, copper wire as a long distance conductor for telegraphs was exploited with success - its advantages and disadvantages in this role however, could only be learnt from experience. Such knowledge as this could only be gained as the telegraph evolved and became established.

S. T. Sommering demonstrated the first voltaic electric telegraph (in proxy through the agency of Dominique Larrey) to the Academie des Sciences in December of 1809, and by 1811 had refined his system sufficiently to establish telegraphic communication over a distance of 10,000 ft. Sommering's conductors of copper and brass wire were insulated with gum lac and silk thread.² Contemporary with Sommering was the Baron Schilling (a one-time associate of Sommering)³ who, in 1812, used "a sub-aqueous galvanic conducting cord" (copper wire insulated with varnish and india rubber) to explode underwater mines.⁴ Some four years later Francis Reynolds (1788-1873) in England, buried copper and brass wires (enclosed in glass tubes) in wooden troughs sealed with pitch. This, in association with overhead iron wire conductors, constituted the transmission system for an electro-static telegraph.⁵

Following a proposal by Schilling, the two Gottingen physicists K. F. Gauss (1777-1855) and W. E. Weber (1804-1891) erected in 1833 a telegraph system to link

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1 Its efficiency as a conductor enhanced its reputation, and since it was a familiar material proven experimentally, it became the optimum choice.

2 Mottelay P.F. op cit p. 407. 3 Ibid p. 420. 4 Ibid p. 421.

5 Ibid. p. 428, see also Fahie J. J. op cit p. 128, also Jrn. Soc. Tele. Eng. Vol. IX Spon, 1880 p. 196.

the town of Gottingen and their observatory. Weber appears to have been the most interested party in this particular project which incorporated over 9,000 (Prussian) feet of copper wire, uninsulated and run over the houses and steeples of the town.¹ This remarkable feat was to inspire C. A. Steinheil to remark of Gauss and Weber that to them was "due the merit of having actually constructed the first simplified galvano-magnetic telegraph".² In the year 1836, Steinheil was invited by Gauss to pursue experiments on the electric telegraph, and in his successful proceedings Steinheil stated for the first time the arguments which determined the type of conductor to be used in telegraphic land lines. The first published notice of Steinheil's invention appeared in the Magazine of Popular Science for 1836³ and both T. P. Shaffner⁴ and J. J. Fahie⁵ carried translations of Steinheil's personal report concerning his work (though the two translations do not compare well) which originally appeared in Sturgeon's Annals for 1839.⁶ Nevertheless, Steinheil's comments on the choice of conductor are as unambiguous in one translation as the other:-

"The conductibility of metals differs - copper for example conducts six times better than iron. The metal most suitable - that which can best subserve the purposes in this technical application - are copper and iron wires.⁷ But though iron is six times as cheap as copper it must be six times the weight to have the same conducting power - thus the expense is the same. The iron is the strongest and the heaviest (but) the preference is given to copper wire as this metal is less liable to oxydation."⁸

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- 1 Poggendorf: Annalen der Physik und Chemie. 32, 568, 1833.
Fahie J. J. op cit p. 324.
Encyclopaedia Britannica op cit Vol. 11 p. 535 - According to Poggendorf the wire was No. 3 gauge.
- 2 Fahie J. J. op cit p. 326.
- 3 The Magazine of Popular Science, Parker - London, December 1836 p. 108-10.
- 4 Shaffner T. P. The Telegraph Manual. London 1859 p. 157-159.
- 5 Fahie J. J. op cit p. 152, 326-329.
- 6 Sturgeon's Annals of Electricity. Vol. 3 p. 439-52 and 509-20, March/April 1839.
- 7 Shaffner T. P. op cit p. 159.
- 8 Fahie J. J. op cit p. 330, see also Shaffner op cit p. 159.

Steinheil's conclusions were based on experiments carried out in 1838, which had used wires of copper run from Munich to Bogenhausen and back; some 32,500ft. of wire weighing 260lbs.¹ (A change of mind may have taken place, however, for earlier, in 1837, Steinheil appears to have utilised iron wire at Munich).² In essence however, a preference for copper wire had been declared by a leading telegraphist, and the world took note. Indeed, there was little reason to contest the results, for all the history of electrical science, and telegraphy to this date had shown that copper was the better choice. Now that Steinheil had additionally shown the economics of the problem it was even more prudent to incorporate copper conductors in a telegraphic system; the role of copper as a first choice conductor appeared well established.

In England, Charles Wheatstone (1802-1875) had culminated a long series of experiments (which had begun in 1834) by forming an association with W. F. Cooke and establishing a telegraph link between the Camden town and Euston Square stations of the North Western Railway.³ Cooke had, himself, experimented with telegraphs but his methods were inadequate, being able to function over less than a mile of conductor.⁴ Wheatstone, on the other hand, was already well versed in the transmission of electrical pulses over very long lengths of wire. This experience had been gained through a series of experiments begun shortly after his appointment as Professor of Experimental Philosophy at Kings College London in 1834.⁵ Wheatstone, following the work of William Watson,⁶ began experiments

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- 1 Shaffner T. P. op cit p. 160 - this wire approximated to No. 18 B.W.G. and was at times run 1,200ft. between supports.
- 2 Fahie J. J. op cit p. 152 - see also the letter page for the "Morning Herald" for September 23rd 1837.
- 3 Latimer Clark J. "President's Address" Jrn. Soc. Tele. Engs. IV, 1875 p. 325.
- 4 Bowers B. "Charles Wheatstone -" Contemporary Physics 16, 1975 p. 508, see also Sabine R. "The Electric Telegraph" Virtue Bros. 1867 p. 36.
- 5 Bowers B. op cit p. 505 - Wheatstone was variously titled at later dates as Professor of Experimental Physics (Dict. Nat. Biog. LX, 436) and Professor of Natural Philosophy (Latimer Clark Jrn. Soc. Tele. Engs. IV, 1875, p. 321.).
- 6 Vide infra Ch. 5 p. 133. Wheatstone acknowledged Watson's antecedence in his paper - see reference 1 p. 586 quoted on page 159 of text.

to establish the velocity of electricity over long lengths of conductor. For this purpose half a mile of copper wire,¹ made up of lengths interspersed with three spark gaps (closely placed) was involved.² The wire was suspended in the vaults under the College³ so as to provide insulation. Sparks caused by a discharged Leyden jar were observed at the spark gaps, which though spatially in close proximity were placed at the beginning, middle and end of the circuit. A speedily revolving mirror allowed the time delay between sparks to be resolved by producing a displaced image during the propagation of sparks across the spark gaps. In so far as telegraphy was concerned, Wheatstone conceded that the practicability of a commercial telegraph system depended on the ability to send signals along very long conductors. He was to write "-if the velocity could be proved to be very great there would be encouragement to proceed,"⁴ Wheatstone continued his experiments over even longer circuits. At Kings College, in June of 1836 he gave, during a course of lectures, a repeat of his earlier experiments before an audience which witnessed transmission over four miles of copper wire (1/16th inch in diameter, No. 16 B.W.G.).⁵ This time, however, Wheatstone disclosed how his circuits might be used as a telegraph by showing the deflection of a galvanometer attached to the end of the circuit. It was reported that for all intents and purposes the circuit was then "fully sufficient for the purposes of telegraphic communications".⁶ From this there followed a series of patents covering the

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- 1 Wheatstone C. "An Account of Some Experiments to Measure the Velocity of Electricity -" *Phil. Trans.* XXIX 1833/4 p. 587 (read June 19th 1834 by M. Faraday) "The conducting wire I employed was of copper, and its thickness the 1/15th inch".
- 2 *Ibid.*
- 3 Wheatstone C. *op cit* p. 587 - "The experiment was tried at the Gallery in Adelaide Street". See also *Dict. Nat. Biog.* LX p. 436.
- 4 Bowers B. *op cit* p. 504.
- 5 *Magazine of Popular Science* Parker - London, March 1st 1837 p. 110 - Writing to P. M. Roget concerning his intentions in making this experiment, Wheatstone stated that he expected to utilise "four miles of iron wire" in addition to the copper "-for the purpose of comparing the velocity of electricity in two different metals". See Bowers B. Sir Charles Wheatstone 1802-1875 H.M.S.O. 1975 p. 47.
- 6 *Magazine of Popular Science* *op cit* p. 110. See also Sabine R. *op cit* p. 36.

signalling through metallic circuits¹ and by 1839 the telegraph systems of Wheatstone and Cooke were well proven. One such system, established between Paddington station and Slough employed five wires of copper held in grooved wooden blocks. A section of this line survives to this day.² By 1840 Wheatstone had long turned his attention to the idea of a practical submarine telegraph and had temporarily forsaken his interest in the further development of overland telegraphs. This work was to be taken up by others, one of whom, S. F. B. Morse (1791-1872) figures highly in the history of the telegraph. But it was to be Morse's associate, and sometime agent, Ezra Cornell (1807-1874) who became important in the history of copper wire.

On the 3rd March, 1843 the United States Congress voted \$30,000³ for an experimental Morse telegraph to be constructed between Washington and Baltimore. At this time Francis O. J. Smith, congressman and lobbyist for Morse, became involved in the mechanics of building the telegraph. His part interest in the American rights to Morse's telegraph resulted in his contracting with Morse to manufacture an underground cable of sheathed copper wires to link the two cities. However, his efforts to move in this direction proved difficult and he did not progress in his attempts to manufacture and lay a "pipe with wires".⁴ In his role as editor of the agricultural paper "Maine Farmer", Smith had met Ezra Cornell in 1841 and Cornell was again received in early April of 1843. Smith was aware of Cornell's mechanical abilities, having come to learn of Cornell's background and having discussed agricultural problems related to Cornell's employment as a sales-

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- 1 British Patent No. 7390 - 12th June, 1837. B.P. No. 8345 - 21st January, 1840. B.P. No. 9022 - July, 1841. B.P. No. 10655 (Electric telegraphs) 6th May, 1845.
- 2 Webster-Smith W. Sixty Centuries of Copper. p. 69 and Plate 36 of the quoted work.
- 3 Fahie J. J. op cit p. 401. Also Dict. Amer. Biog. Oxford University Press 1935, Vol. XIII p. 250.
- 4 Dict. Amer. Biog. Vol. IV p. 444-446.

promoter of the Barnaby and Mooers patent plough.¹ Smith appealed to Cornell to assume control of the cable manufacture (this was to be done using a machine based upon Ried's patent) and to find a way of laying the cable. Cornell took charge of the cable-making machine, designed to cover No. 16 copper wire with cotton insulation, and modified an agricultural plough to dig the cable trench.² Although the cotton insulation on the wire was impregnated with tar, it was soon found that this insulation was inadequate. The cable, when laid down in an experimental site, was found to be penetrated by water and quickly became useless. Cornell suggested that the copper wires in the cable be salvaged,³ cleared of their insulation and strung overhead upon poles.⁴ Cornell took it upon himself to lead a work crew to 'set' and 'reset' the telegraph poles,⁵ having also taken responsibility for both the acquisition of the poles and additional copper wire. After enduring 'hunger - hardship and thirst' for eight weeks, the line was completed.⁶ The first message - 'What hath God wrought' - was transmitted on May 24th, 1844.⁷ Cornell's organisational powers were phenomenal and whilst ostensibly acting in Morse's interests, he went about achieving control over what he considered the heart of the telegraph system - the transmission lines; in this way Cornell made his own position unassailable. His authority in this quarter came about through first hand knowledge of the essential qualities of the components, and the construction of such systems. His credibility in these matters ensured business loyalty - huge

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- 1 Ezra Cornell was born of Quaker parents on 11th January, 1807 in West Chester County, New York. He received a scanty education and eventually found employment first as a carpenter and later as a machinist in Ithaca, New York. (Britannica 13th Ed. op cit Vol. 7 p. 170). His future was ensured through the telegraph and other successful business ventures. Following the creation of the Western Union Telegraph Company and Cornell's presidency which guided the company to prosperity, Cornell turned his financial resources to philanthropy and benefaction, and went on to establish Cornell University which for some years was supported entirely by Cornell's purse. (Dict. Amer. Biog. op cit Vol. IV pp 444-446.).
- 2 Cornell A. B. True and Firm; A Biography of Ezra Cornell. New York 1884 p. 78.
- 3 Smith A. W. Ezra Cornell - A Character Study. Ithaca 1934 p. 38.
- 4 Cornell A. B. op cit p. 78.
- 5 Smith A. W. op cit p. 51.
- 6 Ibid.
- 7 Dict. Amer. Biog. op cit. Vol. XII p. 249.

unprecedented orders for copper wire (rare and expensive) and contracts for telegraph poles made him a valued customer with the wire manufacturers and lumber merchants. Cornell favoured the New York firm of Stephens and Thomas for the manufacture of his copper wire¹ and orders in excess of 9,000lbs. were common.² The wire was gauged at 85-90lbs. per mile and priced at approximately \$1 for 3.5lbs.³ According to Vail, the wire supplied by Stephens and Thomas was "best quality annealed"⁴ but this may be interpreted as 'the best that was available'.

Cornell slowly gained control of very many of the United States telegraph lines; renting or leasing them meant that he retained operational and maintenance interests as well. Through him the sale of copper wire in the United States leapt during the period 1843 to 1846,⁵ but because it departed little from traditional copper wire its deficiencies as an overhead conductor were soon discovered. Poor tensile strength meant the use of more expensive lumber (in the shape of increased quantities of telegraph poles) since every mile of line required more support. In consequence, much more installation labour was necessary and maintenance costs soared.

Copper began to lose the battle as the principal conductor for overhead telegraph lines only two years after the Washington - Baltimore line was completed. The last copper wire telegraph line - linking Philadelphia and Baltimore - was taken down in 1846⁶ (in the interests of economy, constant breakage costing dearly in maintenance) and replaced with iron wire which was stronger. Since copper wire

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- 1 Henry O'Reilly to Ezra Cornell - Letter dated 30th December, 1845. Cornell University Library - Cornell Collection, Dept. of Regional History.
- 2 Amos Kendall to Ezra Cornell - Letter dated 30th November, 1845. Cornell University Library op cit.
- 3 O'Reilly to Cornell op cit.
- 4 Vail A. The American Electro-Magnetic Telegraph; With The Reports of Congress, and a Description of all Telegraphs Known . Philadelphia 1845 p. 13 (B.M. 1398.f.24) and Description of the American Electro-Magnetic Telegraph Now in Operation Between Washington and Baltimore . Washington 1845 p. 6 (B.M. 1398.f.16).
- 5 During this period exports of British copper wire to the United States never exceeded 10 cwt. (1843 - 34lbs., 1844 - 192lbs., 1845 - 412lbs., 1846 - 1,120lbs., 1847 - 590lbs.) See Jrn. House of Commons 1844-1848 Vols. XLV, XLVI, XLVI, LIX, LVIII.
- 6 Article - "American Compound Telegraph Wire" Jrn. Soc. Tele. Engs. Vol. 1 1872/73 p. 284.

had up to this time been used for bell-hanging, as pulley wire, it seems reasonable that its tensile strength in this application was perhaps one reason for discounting thoughts over possible inadequacies when applied to telegraph lines. Whatever the case, the early lines set up by Cornell quickly dispelled optimistic predictions.

Though Cornell, through his indefatigable activities and acute business sense, was to accumulate a fortune from his monopolies, it is notable that he contributed little to the development of telegraph conductors. Indeed, there was none. The copper wire that he purchased was not manufactured as an overhead conductor and behaved poorly in such a role. Having none of the qualities needed for overhead conductors - high conductivity, tenacity and high tensile strength,¹ it quickly displayed its inadequacies and had to be replaced. This copper wire departed little from being a basic, indifferently made material and it is typical of Cornell that loss of profit was the prime motivation in changing to iron wire - no effort appears to have been made to improve the properties of the copper wire though admittedly at this time not enough was understood to affect an improvement. Cornell was intent upon exploiting whatever would produce a quick return on investment and would meet contracts for constructing telegraph lines of high reliability and low breakdown costs. In mitigation, the turmoil of his business activities (which seldom ran smoothly) left him no time for any involvement in the solving of difficult technical problems. Moreover, improvements in wire were the domain of the wire-drawers. Yet, Cornell may well have had the opportunity to subsidise improvements in copper wire; that he

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- 1 It would seem that Vail's description of the copper wire used at this time (best quality annealed) indicates the reason for its principal deficiency; low tensile strength. Hard drawn copper wire has greater tensile strength if left unannealed (i.e. heat treated) though it displays marginally less conductivity than annealed wire. Had this wire been left unannealed, then its durability would have been the greater through its increased tensile strength. However, it should be borne in mind that in these early telegraph systems line conductivity was of paramount importance if signal strength was to be maintained between extended lengths of line.

appears not to have done is evidence of his highly objective attitude to business.¹ For a few short years (1844 - 1846) copper wire appeared to have a future as the principal conductor for telegraph lines in the United States. In this role a traditional staple commodity, with traditional qualities sufficient for such applications, had found a special role which was expected to become established and common. The fact that some thirty years were to pass before this became so was due mainly to the premature application of a material in a role it was ill-designed to fulfil. In the United States very long stretches of wire² demanded the most economic and durable system of transmission line, demands which could not be met by traditionally made copper wire. At this time not even the wire-drawers understood the reasons for the inadequacies of their product and not until 1877 were they, themselves, eventually to solve all the problems of making copper wire totally suitable as an overhead conductor.

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- 1 This is not to say that Cornell was not ingenious, inventive or interested in technical developments - the evidence belies this assertion. His keen mind turned many apparently insuperable problems into inconveniences with simple solutions. From the difficulties of erecting overland telegraphs to the linking of shore lines with submarine cables (which he achieved in 1845 - see Bright C. Reference 3, p. 165 of text) Cornell set himself to solve the attendant problems. However, his pragmatism was directed toward quick and speedy solutions - he seldom grappled with those that needed long term study. Typical of his attitude was his willingness to discuss the characteristics of iron wire in various climatic conditions without regard to improving the wire and thereby raising its durability (Ezra Cornell to F. V. ? Benedict. Burlington, March 23rd 1868 Dept. of Manuscripts, Cornell University - copy of original letter held by DeWitt Historical Society, Ithaca). If copper wire broke or required unacceptably high numbers of poles, and if iron wire could eliminate the problem then so be it - to Cornell that was the solution!
- 2 Where this was no disadvantage however, copper was still used and in 1848 a copper wire was put up to form a telegraph link between Paris and Rouen. See W. H. Preece "On Electrical Conductors" Jrn. Inst. Civ. Engs. LXXV 1883 p. 64.

CHAPTER 7

SUBMARINE TELEGRAPHY AND COPPER WIRE STANDARDS IN THE MIDDLE
19th CENTURY

According to his papers, Charles Wheatstone had as early as 1837 turned his attention to the idea of a telegraphic link between England and the Continent. Wheatstone's son-in-law, Robert Sabine,¹ published in 1876 a summary of Wheatstone's plans for submarine telegraphy which had been formulated between 1837 and 1846.² These showed that Wheatstone had considered almost every aspect of the problem, ranging from the manufacture of the cable to the method of its laying. It is this which establishes Wheatstone as the outstanding initiator of submarine telegraphy (though he cannot be credited with having first transmitted signals under water).³ Nevertheless, few preceded him in practice, and none drew up, nor declared⁴ such detailed plans for crossing the channel with a telegraph cable. As late as 1846, Wheatstone appeared still intent on following through with his plans. Two bills for the manufacture of experimental cable were presented to Wheatstone by a Mr. W. H. Darker of Paradise Street, Lambeth in December 1845 and May 1846. Darker required payment for making experiments "to enclose a copper wire insulated with worsted and marine glue in a lead pipe".⁵ How well Darker met Wheatstone's needs is not known, it appears not to have been at all satisfactory, for by August 1846 Wheatstone had commissioned Henry Mapple to

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- 1 Latimer Clark J. "President's Address" op cit p. 333.
- 2 Sabine R. The Starting Point of Submarine Telegraphy London 1876 p. 1.
- 3 The work of Schilling in 1811 (q.v.), Pasley (1838), Sir William Brook (1839), Morse (1842), Cornell (1845) and West (1846) is well documented in Charles Bright's "Submarine Telegraphs" - Crosby, Lockwood 1898 p. 2-4. See also F. R. Window "On Submarine Electric Telegraphs" Proc. Inst. Civ. Engs. XVI 1857 p. 188-190.
- 4 By 1840 Wheatstone had declared his conviction on the feasibility of a cross-channel telegraph on at least three occasions and had disclosed the method by which it could be accomplished. See Sabine R. The Starting Point of Submarine Telegraphy op cit p. 1-2 and F. R. Window op cit p. 189 who quotes Wheatstone's reply (to a question during the Fifth Railway Report of the Select Committee of the House of Commons) that he believed communication between Dover and Calais "- perfectly practicable".
- 5 Sabine R. The Starting Point - . op cit p. 5.

make 9,000ft. of lead covered cable. Mapple's bill to Wheatstone enumerated the materials used to make "9,000ft. of tube protected wire" as "lead, copper wire, marine glue" and "cotton".¹ Henry Mapple was, himself, quick to see the value of Wheatstone's order. Mapple presented his bill to Wheatstone on the 11th August, 1846² and by the 27th October of that year, Mapple had applied for patents to cover "Improvements In Apparatus For Transmitting Electricity Between Distant Places And In Electric Telegraphs".³ The specification embodied a description of cable manufacture too closely resembling that of Wheatstone's to make it anything other than a plagiarism. In any event, this patent appears to mark the point where Wheatstone's plans lose momentum and he appeared to go no further in the direction of submarine telegraphs.⁴

It was left to the Brett brothers - Jacob and John Watkins Brett (1808-1898 and 1805-1863), to decide finally the matter of a cross-channel submarine telegraph.

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1 Ibid.

2 Ibid.

3 British Patent No. 11, 428 filed 27th April, 1847. Mapple described himself as a machinist of Childs Hill, Hendon in the County of Middlesex.

4 Just as a controversy raged between Wheatstone and Bain concerning originality in the invention of the printing telegraph, so it was said that "Mr. Henry Mapple - had a similar controversy with Mr. Wheatstone respecting an improved alarum and telegraph rope". See Bowers B. Sir Charles Wheatstone. op cit p. 137.

J. W. Brett was to defer to Wheatstone's originality in projecting the idea¹ but assumed the right to claim the honour of carrying out Wheatstone's proposals. The formation of the English Channel Submarine Telegraph Company in 1849 was made possible by personal subscriptions of £500 each from J. W. Brett, Charles Fox, Francis Edwards and Charlton J. Wollaston.² Wollaston, nephew of W. H. Wollaston,³ was appointed as Engineer⁴ to the new company and was despatched first to Birmingham to obtain the copper wire for the core of the proposed experimental cable. He was received at the office of Alfred Sohler Bolton (1827-1901) of the firm

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- 1 i Brett J. W. "On The Submarine Telegraph" Proceedings of the Royal Institution Vol. 2, 1857 p. 394. J. W. Brett could never quite establish his position with regard to Wheatstone's earlier proposals for a submarine telegraph. Only in his 1857 paper (q.v.) did he acknowledge with any generosity Wheatstone's antecedence. In all his other writings there is a hint of "pique" in his mention of Charles Wheatstone. This, perhaps, was the result of some embarrassment when in 1854 he claimed for himself and for his brother (at the British Association meeting in Liverpool) the right to "the honour of being not only the first inventors, but also the first projectors of a Submarine or Oceanic Telegraph". Writing in 1857, in his On the Origin and Progress of the Oceanic Telegraph (W. S. Johnson 1858 p.v) he was to say "to Messrs. Cooke, Wheatstone and Morse - I have ever advocated all honour due; but I must also declare that we were never indebted to any idea from their inventions, and it was only after many years - that I became aware that Professor Wheatstone had put forward an idea - the precise nature of which I am even now ignorant of, having only seen it for a moment for the first time last year (1856) - and not sufficiently to see the principle proposed!" In the same article (p. iii) he states "I - avow that in originating this idea co-jointly - no mans labours or suggestions were borrowed - and I believe I may say (that it was) purely an invention of our own".
- ii. It is worth noting that the shore ends of the Brett experimental cross-channel cable, were to be ultimately very similar to that of Wheatstone's, consisting of .065 inch copper wire covered in cotton, saturated in india-rubber and enclosed in a thick lead tube. See Bright C. Submarine Telegraphs. op cit p. 252 and Willoughby Smith "A Resume of the Earlier Days of Submarine Telegraphy" Jrn. Soc. Tele. Eng. Vol. X p. 316.
- 2 Bright C. "Submarine Telegraphs" op cit p. 6. See also - Newall R. S. "Facts and Observations Relating to the Invention of the Submarine Cable -" Spon 1882 p. 2.
- 3 Bright C. op cit p. 7. Vide infra also p. 150. Wollaston was a former pupil of I. K. Brunel.
- 4 Both Bright and Newall referred to Wollaston as the "Engineer" to the Company - only Bolton (at a later time) was to refer to him as "The Electrical Engineer".

of Thomas Bolton & Sons at Broad Street, Birmingham.¹ Here, Wollaston placed his order for 25 miles of copper wire² insisting that it be made in continuous lengths to weigh 30lbs. per section,³ with a diameter to be equal to No. 14 B.W.G. (.083 inches). At this time, however, as Bolton pointed out to Wollaston, "the only wire produced in copper of that size weighed 4lbs. (per section)".⁵ This appeared to be in keeping with the general convention of selling what was in fact copper bell wire in 60 yard coils or hanks; which for No. 14 B.W.G. would weigh 4lbs. per 60 yards. So outrageous was the order A. S. Bolton recounted, that:-

"- the foreman who was sent for to receive instructions, when he heard what was required, said, "Does the man think I am a fool?" - so impossible did he consider its production".⁶

In truth, the foreman was to be proved right and Wollaston's demands could not be met. The copper wire arrived at the Wharf Road Works of the Gutta-Percha Co. (where it was to be insulated) in indifferent lengths mostly approximating to 100 yards⁷ (6.26lbs. of No. 14 B.W.G.). This was to necessitate almost six times the number of joints, between individual lengths, that had been expected. The method of joining, or jointing, was known as a Bell-Hanger's Twist which consisted of taking the two ends of the wire and coiling one about the other, finally securing the joint with molten

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1 Vide supra Ch. 8 p.196.

2 Willoughby Smith "A Resume of the Earlier Days of Submarine Telegraphy" Jrn. Soc. Tele. Engs. Vol. X 1881 p. 316.

3 Bolton A. S. "Discussion on Electrical Conductors" Proc. Inst. Civ. Engs. Vol. LXXV 1883 p. 100.

4 Willoughby Smith "Resume -" op cit p. 316. This would approximate to some 480 yards in length.

5 Bolton A. S. op cit p. 100.

6 Ibid.

7 Willoughby Smith "Resume -" op cit p. 316.

soft-solder (see Plate 47).¹ The reliance on traditional methods of jointing was, in essence, unsatisfactory, as too was the quality of the copper itself. Willoughby Smith (1828-1891), who was to become a successful telegraph engineer, recalled that his beginnings at the Gutta-Percha Company came by way of his acting initially as Pot (or Beer) Boy for overtime workers.² Shortly after he had the luck to find full employment with the Gutta-Percha Company (1848)³ he witnessed the manufacture of the submarine cable for the Bretts, and was later to comment in 1891:-

"Unfortunately many things were at that time thought to be perfect which would not now pass muster, for example, the wire drawers of those days, strangers to long lengths and proper annealing, appeared to take it for granted that the Birmingham wire gauge was any gauge they chose to make it, the result being that the diameter of the wire varied considerably even when supplied by one firm."⁴

This was, however, a mild comment compared to earlier remarks. Willoughby Smith variously described the copper wire of this time as lacking in "continuity, caused by the presence of foreign matter in the copper, rottenness from being burnt while annealing and numerous other causes".⁵ At best, he wrote, parts in

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- 1 Ibid. This is clearly further evidence of the role of traditional practices (used in connecting copper bell-wire in the trade of Bell Hanging) which was the only experience that could be relied on when handling copper wire. See also, for further comment on this, Willoughby Smith Jrn. Soc. Tele. Engs. Vol. V 1876 p. 257.
- 2 Dictionary of National Biography LIII p. 168. See also Lawford G. L. and Nicholson L. P. The Telegraph Construction and Maintenance Company - The Telcon Story 1850-1950. Fanfare Press 1950 p. 29.
- 3 Dictionary of National Biography LIII p. 168.
- 4 Willoughby Smith. The Rise and Extension of Submarine Telegraphy. J. S. Virtue & Co. 1891 p. 1-2.
- 5 Willoughby Smith "On Underground Telegraphs" Jrn. Soc. Tele. Engs. Vol. VI 1877 p. 164.

any one length might vary through "hard, brittle, soft and rotten".¹ (We may suppose that the American firm of Stephens and Thomas, who had supplied Ezra Cornell in 1845, could do no better. No wonder then that he turned to iron wire!)

If the wire supplied by Thomas Bolton was as poor as we are led to believe by Willoughby Smith, it should not be taken as completely the fault of the makers - no firm electrical or mechanical specification was made;² nor would there be for any cable for a number of years. Variations in the mechanical quality were soon to be improved upon, but at the time of the experimental cross-channel cable the copper wire manufacturers supplied material which was suitable for the traditional purposes to which it was put i.e. bell-hanging etc. The dimensions of copper wire-bars (copper ingots) provided by the smelters were designed to deliver rolled sheet (or battery plates) which, when slit could be drawn down into wire approximating to a standard length. The lengths of drawn copper wire were convenient for the crude draw benches and annealing ovens then in use. Brazing together sections of slit copper sheet so as to draw longer lengths was contrary to traditional needs. Improvising upon well established production methods meant overcoming the limitations of existing draw benches and required much effort in extending the size and precision of annealing ovens, and annealing processes. This required time and experience. As Willoughby Smith was again to note:-

"Those who supplied the copper wire were anxious to do their best but (still) their wire was irregular in gauge and annealing -".³

The supply of copper wire for bell-hanging was to give way to the making of wire for submarine cables; a different art altogether. Nevertheless, Boltons worked hard and

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- 1 Willoughby Smith. - Rise and Extension -. p. 13. See also the report of the Joint Committee Into Submarine Cables Jrn. House of Commons Vol. LXII (1860) p. xiv which supports Willoughby Smith's assertions and refers to the fact that "Copper could not be procured of homogeneous texture and not only did hard and soft places occur but defects on the presence of foreign matter frequently made the wire so weak that it ultimately parted -".
- 2 The laxity in this direction resulted eventually in the Atlantic cable of 1857 being made with two halves (from different manufacturers) having twists in the armouring of opposite direction. See Bright C. "Submarine Cables" op cit p. 35. See also footnote (1) and text, p. 219.
- 3 Willoughby Smith. - Rise and Extension -. p. 13.

it might be closer to the truth to propose that the bright drawn copper wire was not quite so badly produced. Certainly not so bad as to dissuade curious bystanders at Dover from cutting into the insulation of the completed cable so as to reveal the bright copper wire, nor to stop them from stealing sections of it.¹ Indeed, the final destruction of the cable appears to have been perpetrated by a Boulogne fisherman who raised up the laid cable in his nets just a few hours after it had been put down, and thinking that he had discovered a snake, or such like, with "gold in it centre" cut out a length.²

For submarine telegraphy to progress, it was essential that the overall reliance on traditional methods of manufacturing wire be changed. The experience of years would leave behind copper bell-wire - jointing by Bell-Hanger's twists and the misconceptions held by many at this time that the submarine telegraph was mechanical in nature. (In regard to this, some critics concluded, from the predominance of bell-hanging tradition surrounding the cable, that the method of signalling was similar to that of operating house-bells, and that the channel bottom was too rough to accomodate such a procedure).³ However, whereas the mechanical condition of the copper wire might be immediately apparent by visual inspection, its electrical qualities (especially conductivity which affected signal strength and speed) were ignored. So wanting were these early cables that the experimental cable of 1850 was credited with a minimum conductivity of 30%⁴ while a conductivity of 40%⁵ (as compared to the 100% of pure

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- 1 Lawford G.L./Nicholson L.P. - The Telcon Story - op cit p.31 It is worth recording that an innate fascination was found in the populace on both sides of the Atlantic - just as curious bystanders had stolen sections of the 1851 cable, this interest was turned to profit in 1858 when the New York firm of jewellers 'Tiffanys' bought 20 miles of the 1858 Trans-Atlantic cable (Vide supra) and cut it into small sections for sale as curiosities. (Letter from C. W. Field to W. Thomson dated June 29th 1859. University Cambridge Library Add 7342).
- 2 Illustrated London News: September 27th, 1851 p. 397. See also Bright C. Submarine Telegraphs. op cit p. 9. It is interesting that R. S. Newall (op cit p. 2) claims that the cable was broken by "chafing on the rocks", and this is supported by a report in the Mechanics Magazine No. 1414 (Vol. 53) for September 14th, 1850 p. 234.
- 3 Willoughby Smith. - Rise and Extension -, op cit p. 5. See also Bright C. Submarine Telegraphs: op cit p. 10 and the 8th Edition of the Encyclopaedia Britannica (Black-Edinburgh 1860) which states (Vol. 7 p. 351) "Copper is drawn into wire, used for communication with the bells in houses and for other purposes".
- 4 Bright C. Submarine Telegraphs. op cit p. 221.
- 5 Ibid. p. 54

copper) was the norm. For some of the wire supplied to the Gutta Percha Company for the manufacture of the second Dover/Calais cable (1851) a conductivity of 42% was reported¹ while in some underground telegraphs, using wire similar to that used in the submarine cables, conductivities as low as 18%² were found. Copper, it seems, was copper, as Willoughby Smith observed of the experimental submarine cable of 1850:-

"To its electrical condition and quality no attention was given, for the simple reason that all copper wire was credited with the possession of equal value in these respects".³

From 1850 small improvements in the quality of copper wire used in submarine telegraphs did occur - the first Anglo-Irish cable laid between Portpatrick and Conaghadee in 1852 has a conductivity estimated at 46% while the first Atlantic cable (1857-58) was formed from lengths of copper wire (No. 22 B.W.G.)⁴ which exceeded one mile per reel⁵ and had an average conductivity estimated at between 45%⁶ and 50%.⁷ Some part of this improvement may be attributed to the wire-drawers who had now the experience of five years wire-drawing for submarine cables. Familiarity with the problems of earlier wire making resulted in an improved product, exemplified in copper wire consistent in its mechanical quality throughout much extended lengths.⁸ The 100 yard hanks (coils) of 1850 had given way by 1857 to reels of copper wire one mile in length.⁹ A consequence of this improvement in mechanical

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- 1 Preece W. H. "Electrical Conductors" op cit p. 65.
- 2 Willoughby Smith "Resume -" op cit p. 164.
- 3 Willoughby Smith. - Rise and Extension -, op cit p. 1-2.
- 4 Bright C. Submarine Telegraphs. op cit p. 35.
- 5 Illustrated London News. March 14th, 1857 p. 244.
- 6 Bright C. Submarine Telegraphs. op cit p. 74 and 221.
- 7 Preece W. H. "Electrical Conductors" op cit p. 65.
- 8 This was not entirely due to a reduction in gauge from No. 14 B.W.G. (1850) to No. 22 B.W.G. (1857).
- 9 Illustrated London News. March 14th, 1857 p. 244. Strictly speaking this refers to the stranded copper wire rope made up from individual lengths of copper wire. Nevertheless, it speaks well of the improvements achieved by this time.

quality was an improvement in the electrical conductivity, for as William Thomson (1824-1907) observed "- a good mechanical quality was necessary to prevent frequent fractures in the wire drawing" - "the worse metal being found to break before it could be drawn into a hank of a certain size".¹ Invariably, copper that could be well drawn was both purer and had a higher conductivity than that which broke upon drawing and had to be discarded.

Though the quest for a copper wire with better mechanical qualities was to produce wire with some improved conductivity, the most determined research in this matter was carried out by William Thomson (later Lord Kelvin of Largs) who had maintained an interest in submarine telegraphy from its inception. It was J. and W. Thomson, who with the aid of W. J. Rankine, had formalised a provisional specification for stranded conductors in 1854.² This form of conductor was suggested publically by Thomson, on November 29th, 1854, at a meeting of the Philosophical Society of Glasgow³ and though the patent was abandoned (perhaps in the face of wire rope patents held by R. S. Newall (1812-1889)) the first stranded submarine cable was laid between Cape Breton and Newfoundland in 1856. This cable consisted of a seven strand conductor, embodying Thomson's idea that a stranded conductor achieved better flexibility; it avoided the risk of a fracture in any one strand, interrupting the transmission of signals.⁴

In November, 1856, the Board of the Atlantic Cable Company was formed, one of the Directors being William Thomson.⁵ Three hundred and fifty ordinary shares of £1,000 acted as the base capital for the initial order to the Gutta Percha Company

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- 1 "Report of Joint Committee - to Enquire into the Construction of Submarine Telegraph Cables" Jrn. House of Commons (Eyre and Spottiswoode) Vol. LXII 1860 p. III. Thomson had earlier made a similar remark in 1857 when in his paper "On The Electrical Conductivity of Commercial Copper -" (Proc. Roy. Soc. Vol. VII 1858 p. 552) he stated:- "Wire - supplied by different manufacturers as remarkably pure; and being found satisfactory in mechanical qualities had never been suspected to present any want of uniformity as to value for telegraphic purposes
- 2 British Patent No. (provisional) 2547, 1854.
- 3 Thomson W. "Telegraph" Encyclopaedia Britannica 8th Ed. op cit Vol. 21 p. 96.
- 4 Bright C. Submarine Telegraphs p. 27 and 227. See also Thompson S. P. Life of Lord Kelvin Macmillan 1910 Ch. VIII p. 349.
- 5 Brett J. W. On the Origin and Progress of the Oceanic Telegraph W. S. Johnson 1858 p. 49.

for the construction of the cable. The order was given in February of 1857 and within four months the cable had been completed! The specification required a core to be made of seven No. 22 B.W.G. copper wires (a total diameter equal to No. 14 B.W.G.) weighing 107lbs. per nautical mile. In all, 119.5 tons of copper had to be drawn into 20,500 miles of wire which had then to be "laid up" into a strand 2,500 miles long.¹ Though the wire drawers in Birmingham² could deservedly congratulate themselves on this remarkable achievement, they would have been vexed to be told of the deficiencies (in the electrical conductivity) of their efforts. Some members of the Board felt more time should have been allocated to the manufacture of the cable. Indeed, an entirely different specification based on a longer manufacturing time, had been proposed by E. O. W. Whitehouse³ while Charles Bright⁴ urged that the cable be formed with a core having "a copper conductor composed of seven equal wires of maximum purity stranded together, of such a gauge as is equivalent to a weight of 392lbs. per nautical mile".⁵ Unfortunately, the size of conductor had been settled before Bright had been appointed,⁶ and it is interesting to speculate on whether or not the cable would ever have been made, had Bright's specification stood. The conductor would have been approximately four times as expensive to make and Bright's requirement for "maximum purity" - a term almost unheard of - would undoubtedly have led

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- 1 Bright C. Submarine Telegraphs. p. 34-35.
- 2 Thomas Bolton and Sons now (1853 and thereafter) at Oakmoor, see Ch. 8 p. 196.
- 3 Founder and electrician of the Atlantic Cable Company.
- 4 Founder and engineer in chief to the Atlantic Cable Company.
- 5 Bright C. p. 35.
- 6 Dictionary of National Biography Vol. 1 (supplementary) p. 272.

to a severe delay in the laying of a Trans-Atlantic cable.¹ As it was, the problems surrounding this exercise were to be the province of William Thomson, a man of high ability, who turned to the question of the relative conductivity of copper during his period as a Director of the Atlantic Cable Company. Thomson was to be well suited to the task but was not the first to become aware of it. Warnings over the need to exercise care and judgement over the choice and quality of the copper for submarine cables had been given before either Bright or Thomson. J. Latimer Clark (1822-1898)² had written, early on in the formation of the Atlantic Cable Company, to the General Manager of the Company (Mr. Cyrus Field) and the Works Manager of the Gutta Percha Company - Mr. Statham. In his letters, Clark had advised most strongly against the use of brass wire in place of copper and "earnestly to be aware of having a wire of bad conductivity".³ Whereas Latimer Clark appeared to be satisfied with what eventually was decided upon as the conductor (he seems to have let the matter rest after his letter) his activity may have stimulated William Thomson, to some degree. Thomson had, as he says, "accidentally noticed differences greater than I expected in the conducting powers of one or two samples which I had had previously".⁴ The samples, to which Thomson refers, were pieces of copper wire from coils supplied to the Gutta Percha Company and intended for the 1857 Atlantic

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- 1 It appears that some note was taken of the calls for high purity, at least insofar as a paper specification was concerned. The conductors, it was claimed "were made of the purest copper -" and that the "- copper wire (was) assayed from time to time during the manufacture to insure absolute homogeneity and purity". (The Atlantic Telegraph - A History of Preliminary Experimental Proceedings Jarrold and Sons - July 1857 p. 39). This came some eight months before Thomson was able to detect what this specification supposedly called for!
- 2 At this time Electrician to the Electric and International Telegraph Company, and later to become a Telegraphist of some note. He was also the inventor of the Clark Standard Cell and he took a leading part in the systemisation of electrical standards. See Britannica Vol. 6 p. 442.
- 3 Report of the Joint Committee into Submarine Cables p. 206.. See also Bright C. Submarine Telegraphs p. 216 who says "It is believed that Mr. Latimer Clark was one of the first to bring to light the wide variation existing between the conductivity of different species of copper".
- 4 Report of Joint Committee p. 111.

telegraph. At Thomson's request, more samples were supplied and as he later related:-

"Calling the best specimen which I had in the summer of 1857 100, I found many specimens standing at 60 in specific conductivity, many standing at 50, many standing at 80, and so far as I can recollect the average stood between 60 and 70".¹

Thomson continued his investigations and with the aid of his "laboratory corps"² engaged upon a wide reaching research exercise covering the quality and conductivity of various grades of commercially available copper wire. In June of 1857, Thomson prepared his results and published them.^{3, 4} His paper "On the Electrical Conductivity of Commercial Copper of Various Kinds" showed that he had compared wire and "strands (of wire) spun from it"⁴ from four manufacturers. After briefly considering the reasons for his investigations⁵ Thomson went on to disclose the variations between samples as supplied by the manufacturers - some wires of equal gauge were almost twice the resistance (half the conductivity) of others. It was found however, that there was a degree of consistency between samples from any one manufacturer and to this Thomson remarked "- there is vast superiority in the produce of some manufactories over that of others - a submarine telegraph with copper wire of the quality of manufactory A of only 1/21 in diameter, would do more telegraph work than one constructed with copper wire of the quality D of 1/16 in diameter".⁶ One of the wires of low conductivity was assayed and found to contain only

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1 Ibid.

2 Thompson S. P. Life of Lord Kelvin p. 340.

3-4 Thomson W. "On the Electric Conductivity of Commercial Copper of Various Kinds" Phil. Mag. XV (1858) p. 472-476 and Proc. Roy. Soc. VIII (1858) p. 550-555.

5 Ibid. "In measuring the resistances of wires manufactured for submarine telegraphs I was surprised to find differences between different specimens so great as must materially to effect their value in the electrical operations for which they are designed".

6 Ibid.

traces of Lead, Iron and Antimony/Tin.* "If chemical composition is to be looked to for the explanation, very slight deviations from perfect purity must be sufficient to produce great effects on the electric conductivity of copper".¹ Apart from this point however, Thomson did not, at this time, lay further emphasis on the issue. The matter of copper purity was to remain in the background for a short period. Concluding his first paper on the subject, Thomson said that even the worst of the wires intended for telegraph work were superior in conductivity to some other qualities of commercial copper and comparing his wires to the available copper standards; as supplied by Jacobi, Weber and Kirchhoff the specimens stood up reasonably well.²

The comparison between Thomson's samples and the standard wires of Weber, Kirchhoff and Jacobi was not accidental nor merely trimmings to the factual evidence already available. Thomson was later to point out (17th December, 1859)³ that he was conscious of a disclosure by W. Weber "many years before" that there existed "considerable differences in different specimens of copper wire".⁴ Apart from his telegraphic work involving copper conductors, W. E. Weber⁵ had had further reason to take account of the quality of copper wire. In 1848 M. H. von Jacobi in an attempt to avoid the multiplicity of standards rife at this time, circulated an especially prepared copper wire to be used as a standard of resistance.⁶ Though Weber was not to be satisfied with this (he preferred an absolute measure of resistance), receipt of the Jacobi

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1 Ibid p. 552.

2 Ibid p. 555.

3 Report of Joint Committee Into Submarine Cables op cit p. 111.

4 Ibid. (This can be dated prior to 1852, for in a paper for that year (On The Dynamical Theory of Heat Phil. Mag. IV 1852 - 118 Art. XLVIII) Thomson refers to Weber's result that "The specific resistance of different specimens of copper - differ considerably from one another".)

5 Vide infra Ch. 6 p. 156.

6 Poggendorff Annalen der Physik und Chemie LXXXII (1852) p. 337.

* The similarity between the composition of the rare mineral bournonite and the impurities in this sample of Thomson's indicates that the copper was mined originally in Cornwall. Bournonite is a sulphantimonite of lead and copper containing antimony, lead and copper, and is to be found in the old copper, tin and lead mines of Cornwall.

standard provoked greater thought on the matter¹ by Weber, and his comments were to later influence Thomson. However, though Weber was to impart the germ of suspicion in Thomson's mind over the quality of wire for the Atlantic cable, this had originated quite probably over Weber's rejection of various arbitrary standards (such as Jacobi's which he felt should not be trusted when duplicated) rather than as a comment with commercial wire in mind.² Nevertheless, whatever the accuracy of Thomson's recollections, the result was to reinforce his belief that the copper wire was not all that it could, or should be. However, Thomson's initial exploration of the subject was temporarily halted when in early August of 1857, he agreed to act as replacement³ electrician on board the 'cable ship' Agamemnon - a battleship lent by the Government and fitted out to lay a half section of the Atlantic cable. Two attempts to lay the cable failed and the cable fleet returned to port with 385 miles of cable irretrievably lost.⁴ Though Thomson was disappointed over the abandoned attempt, it gave him the opportunity to proceed with the many projects pressing at this time. He continued his investigations into copper wire on his return to Glasgow University, turning over much of the work to his students in their part-time capacity as laboratory assistants. (At any one time there could be between a dozen and twenty people working in the laboratory).⁵ Specimens continued to be delivered to Thomson and the story was much the same. "Still in the Summer of 1857 I received specimens of wire which were in stock for

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- 1 For further comment on Weber's (and others) outlook, see the Dictionary of Scientific Biography. (Scribner- New York) XIV (1975) p. 206. et seq and Fleming Jenkin in 'Reports of the Committee on Electrical Standards'. E. and F. N. Spon (1873) p. 192.
- 2 Thomson had pointed out that Weber had noticed differences in different specimens "he had tested", and that Thomson, himself, had found "differences much exceeding those -". (Report of Joint Committee into Submarine Cables op cit p. 111). This 'excessive' difference indicates that Weber was probably not referring to commercial wire.
- 3 Whitehouse - the official Electrician to the Company - was unable to accompany the expedition, ill health was blamed.
- 4 Bright, Sir C. T. Dictionary of National Biography supplementary Vol. 1 p. 272.
- 5 Murray D. 'Lord Kelvin as Professor in the Old College of Glasgow. Madchose, Jakson 1924 p. 14.

submarine telegraphs - for some of the Mediterranean telegraphs I believe - which stood as low as 43"¹ against a best specimen of 100. (In all, Thomson was to see conductivities ranging between 37 and 100 over the period July 1857 to July 1858).² Nevertheless, by January of 1858, Thomson was no nearer an understanding of the cause of this variability in his samples - at least not with any degree of certainty. He had ensured, however, that the 700 miles of new cable ordered to replace that lost in the first expedition be made under a contract which required the use of "high conductivity" copper wire. The insertion of this clause was a triumph for Thomson. Whitehouse had vigorously opposed the need for such formalities, and an "apathetic"³ board of directors preferred to accept his view that the resistance of the conductor would not affect the speed of signalling.⁴ "Not until he (Thomson) took up an obstructionist attitude" we are told "and persevered at successive meetings in opposing all other business, did they listen to his insistence on proper testing of material".⁵

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- 1 Report of Joint Committee into Submarine Cables op cit p. III.
 - 2 Thomson W. Popular Lectures and Addresses Macmillan 1891 Vol. 1 p. 451.
 - 3 Thompson S. P. op cit p. 350.
 - 4 This was an area of thought where Thomson was opposed by Faraday and Whitehouse, but ably supported by S. A. Varley, who, in a paper read to the Institute of Civil Engineers ("On the Electrical Qualifications Requisite in Long Submarine Telegraph Cables" Proc. Inst. Civ. Engs. XVII 1858 p. 385) pointed out "That the wire should be made of the best conducting material that can be obtained, so as to reduce - the induction to a minimum - (since) rapidity of action will be obtained (as) the resistance is lessened".
 - 5 Thompson S. P. op cit p. 350/351. By October 1858, opinion in the Atlantic Telegraph Company finally turned against Whitehouse. In a letter to William Thomson on October 9th 1858, the Company Secretary (George Seward) said "- the Committee - say that they think the directors as a body had better have nothing further to do with Whitehouse as he will not be convinced by anything they may say - they think it would be perfectly correct on your part to disabuse the public upon the scientific errors into which Whitehouse has fallen -" (Stokes-Kelvin Collection - University Library Cambridge Add. 7342/A109).
- * Gray A. (Lord Kelvin, Dent London 1908 p. 266) was to say "Thomson's view prevailed and the result was the establishment first by Thomas Bolton & Sons - of Mills for the manufacture of high-conductivity copper - which is now a great industry. There was now a distinct difference between the original calls for "high purity" copper (which could not be easily tested) and "high-conductivity" wire (which could be tested) and it necessarily followed that "high-conductivity" wire would tend toward high purity in any case.

The Gutta Percha Company, who made the core, only consented to comply with the more stringent specification at an increased price. Naturally enough, since testing apparatus had to be set up and many hanks of wire might be rejected as below standard.

The secretary of the Atlantic Cable Company, Mr. Seward, wrote to Thomson on 6th October, 1857:-

"I fear that difficulty in carrying out your views about Copper will arise from the Gutta Percha Company who state that they cannot contract to deliver within a specified time if the close examination you contemplate is to be undergone".¹

On a more encouraging note however, he wrote on the 20th October:-

"The conductivity question is occupying the best attention of all of us - every hank of wire is being carefully tested to a given standard. The attention of the most eminent smelters is being directed to the matter and they have been invited to the Gutta Percha works to see for themselves the variations in conducting power of the several parcels sent in".²

Interestingly, Thomson had urged the need for the copper smelters (who supplied copper to the wire-drawers) to appreciate the varying quality in copper. It would appear that Thomson realised that different ores produced copper with varying degrees of impurity and that it was this, which affected the conductivity of copper wire. In January 1858, Thomson addressed a meeting of the Glasgow Philosophical Society. There he demonstrated the method of testing conductivity in copper wire using a similar apparatus to that used at the Gutta Percha Company. The use of the testing procedure, he said, resulted in the best conductivity wire being used in place of the worst - a difference in cost of £100,000.

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1 Ibid.

2 Ibid. W. H. Preece in his "Submarine Cables" (Proc. Inst. Civ. Engs. Vol. XX 1860-61 p. 39) remarked "In the copper wire supplied to the Atlantic Telegraph Company, some lengths varied as much as 40%. The attention of the Gutta Percha Company having been called to this fact, a considerable improvement in the quality of Copper supplied has been the result; every mile - is now carefully tested. The No. 16 copper wire of the present day conducts better than that of the standard used, (Vide supra p. 190) in the proportion 3 to 2".

He could not explain the reason for the diverse values for conductivity in copper wire - wires from the same manufactory differed in conductivity, and chemical analysis showed no difference in composition.* The state of "crystalline aggregation" had no effect - stretching, twisting or compression in no way affected the conductivity. "The cause of the difference must be held as still entirely unexplained".¹ The whole subject, he maintained, "was still involved in complete mystery, while the facts were undoubted and of the utmost practical value".²

Thomson's over honest admissions may have been tongue-in-cheek, not altogether a deception, but perhaps a reaction to an intuitive belief that he had identified the reasons for the variance in his samples, and that confirmation was soon to be had. No doubt finding his own facilities lacking, and needing the expertise of a renowned chemist, Thomson had despatched five specimens of No. 22 B.W.G. copper wire to A. W. Hofmann (1818-1892) at the Royal College of Chemistry, with a view to having the most exacting analysis of their composition carried out. On 10th March, 1858, Hofmann replied to Thomson setting out his findings. A very meticulous analysis, repeated many times, had allowed Hofmann to form the conclusion that:-

"- the diminution of conductivity observed in certain specimens of copper is due to the presence in these specimens of a certain amount of foreign matter and not, as it has been supposed, to a peculiar change in the physical condition of the metal".³

The five specimens had been found to have conductivities of 42, 71.3, 84.7, 86.4 and 102 against a standard sample designated 100.⁴ Thomson could clearly see that this

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1 Thomson W. "The Conductivity of Samples of Copper Wire" Proc. Glasgow Philosophical Society Vol. IV No. 1 (1858) p. 185 - read January 13th, 1858.

2 Ibid. p. 186.

3 Thomson W. "Analytical and Synthetical Attempts to Ascertain the Cause of the Differences of Electrical Conductivity Discovered in Wires of Nearly Pure Copper" Proc. Roy. Soc. Vol. X (1859-60) p. 302.

4 Ibid. p. 301.

* E. O. W. Whitehouse was to remark at this time "During the manufacture of the cable Professor Thomson drew my attention to certain variations in the conducting power of different specimens of copper wire, amounting in some instances to as much as 45-50% while yet no proportionate chemical impurity could be detected" - Whitehouse E. O. W. The Atlantic Telegraph. London 1858 p. 12-13.

vindicated his theory; the electric conductivity was "in order of the purity of the copper".¹ Poor analytic techniques previously experienced by Thomson could not have discovered the 0.1 to 1.24%² of impurities that accounted for the great range of conductivities. The difficulties experienced by Hofmann had been great - he carried out "what proved to be a most troublesome investigation" Thomson remarked.³ Even so, Hofmann had only ascertained, with any degree of confidence, the percentage of copper in the samples and thus the percentage of impurities - the identity of the impurities could still not be established. Thomson made attempts to remedy this by having alloys prepared from the "purest" copper⁴ and various other metals. The results were inconclusive however, but indicated at least how very small quantities of metallic/metalloid impurities could produce extreme variations in the conductivity of copper. Though Thomson was to go no further in these particular investigations, his work in this period had nevertheless been, up to this time, a small triumph and he was later to say:-

"From that time (October 1857) to the present there has never been a question on the part of either companies or contractor as to the necessity for the stipulation of 'high conductivity'; and a branch of Copper manufacture has grown up in the course of these twenty six years for producing what is called in the trade 'conductivity copper' ".⁵

Thomson deservedly took credit for revealing the deficiencies in copper wire used for telegraphic purposes, but his contribution was not entirely all that was necessary for the

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1 Ibid p. 302.

2 Ibid p. 301.

3 Ibid p. 300.

4 Ibid p. 302-305. Some question over Thomson's samples of "pure copper" arises here. The metal was supplied by the firm of Johnson and Matthey. Thomson mentions that he noticed a difference in the conductivity "of two specimens of electrottype copper" (Ibid p. 303). The cause being undiscovered.

5 Thompson S. P. op cit p. 351.

total of improvements that were to take place up to 1883¹ when he spoke of his role. The Atlantic cable of 1865 was manufactured with a core having a conductivity of "at least 85% of that of chemically pure Copper".² Though some of the credit for this improvement belongs to Thomson, the basis for it was to be found in the electrical testing of wire at the cable works, rather than an overall improvement in the quality of the wire. To enable the smelters to improve the performance of wire for cable work, more needed to be known about copper and why it was that one smelter could supply a metal of higher purity than another. Many similar questions needed to be answered - especially the outstanding one concerning the exact effect of metals when alloyed in trace concentrations with copper. A concerted attack upon this problem was made in the period 1860-1864 by Augustus Matthiessen (1831-1870) who began by publishing with C. Vogt^{*} (as co-author) a paper "On the Effect of the Presence of Metals and Metalloids upon the Conducting Power of Pure Copper".³ This inquiry had been published as a result of the formation of a Joint Committee to inquire into the construction of submarine telegraph cables after the failure of the 1857/58 Trans-Atlantic cable. The Committee appointed Matthiessen to follow Thomson's work in copper, pointing out that:-

"Professor Thomson and other experimenters have shown that the quality of the Copper exercises an important influence on the conductivity power of Copper wire; but this question had not been fully developed when we commenced our inquiries; we consequently committed to Dr. Matthiessen the task of elucidating this question further".⁴

Matthiessen's report to the Committee was communicated in April of 1860 and was no less than scientifically devastating. Any form of impurity was shown by Matthiessen to effect the conductivity of copper - "no alloy of Copper - conducts electrically better than

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1 Ibid.

2 Bright C. op cit p. 82. See also Ch. 8 p.196 for further details on the 1865/66 Atlantic Cable and Preece W. H. "On Electric Conductors" op cit p. 65 who quotes an average conductivity of 96% for the 1865 cable.

3 Matthiessen A. & Vogt C. Phil Trans. 1860, CL, p. 85.

4 Report of the Joint Committee into Submarine Cables op cit p. XV.

* Matthiessen also numbered among his colleagues Von Bose and Hockin as well as Vogt, and his original interest was in discovering an alloy having a higher conductivity than copper.

the pure metal".¹ Samples of the principal ores generally used by British smelters were supplied by Latimer Clark² and of these a specimen of Spanish (Rio-Tinto) ore had a conductivity of 14.24 - approximately that of iron. The submarine cable manufacturers, said Matthiessen, should use "the purest copper" the best and surest method of bringing this about would be to "- contract for such cables at so much per knot of a certain resistance".³ The smelters and wire-drawers then, were to have little excuse. The best ores, such as Lake Superior (called "native metal" since it is found in a metallic state)⁴ were to be called upon since the amount of preparation and refining to prepare a high grade copper was comparatively small. Here, Matthiessen had shown that the initial conductivity was high, some 92.57% and the impurities correspondingly low. The lower grade ores would not answer to refining so well. Though Matthiessen had shown that the smelters' habit of adding a small amount of lead to their copper was beneficial,⁵ it was only so in those ores with a large proportion of copper oxide (the "suboxide" of copper). In these cases the lead reduced the oxide without combining with the copper.⁶ Ores with a large level of copper oxide would have their conductivities improved, within limits, by the addition of lead, and, as he consequently demonstrated, tin.⁷ However, since ores with high copper oxide invariably coupled this with equally high levels of other impurities (such as arsenic) very high conductivities were extremely difficult to achieve.* The

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1 "Report of an Investigation relating to the Causes of the Different Electric Conducting Powers of Commercial Copper" Matthiessen A. Joint Committee into Submarine Cables op cit p. 335.

2 Vide infra p. 175.

3 Matthiessen A. On the Conducting Powers of Commercial Copper Ibid p. 337.

4 Bright C. op cit p. 218.

5 Matthiessen A. On the Conducting Powers of Commercial Copper p. 336.

6 Perrin F. A. "Conductors for Electrical Distribution" Von Nostrand 1903 p. 8.

7 Matthiessen A. On the Conducting Powers of Commercial Copper p. 336.

* Even careful smelting of ores sometimes produced unexpected and inexplicably poor results. Homogeneity and mechanical quality could not always be controlled; even though close attention was paid to providing a pure smelt in expectation of a high purity copper. The phenomenon known to smelters as "copper rain" - the projection of droplets of molten copper from the smelt - usually resulted in a porous low density copper. This was explained first by Dick in 1856 (Phil. Mag. June 1856) but more properly by Russell and Matthiessen in 1862 when experiments showed that copper rain was due to outgassing in the smelt through the production of carbon monoxide (during the reduction of copper oxide by influxed carbon). (Russell W. S. & Matthiessen A. "On the Cause of Vesicular Structure in Copper" Phil. Mag. 23, (4th series) 1862, p. 81-84).

wire-drawers too, could take note of Matthiessen's report. Hard-drawn copper wire was inferior, in conductivity, to that of properly annealed wire by some $2\frac{1}{2}\%$.¹ Poor attention to the correct heat treatment of copper wire might result in high costs and penalties to the wire-drawer making wire for electrical purposes:-

"It is well known that the wires of some metals require much more care in drawing than others; thus copper and silver, if not annealed often enough during the process of drawing will often become quite brittle and break off short when bent - cavities will be found - and when great care is not used, and the wire drawn by different persons - conducting powers are often obtained which vary by several per cent".²

It was thus becoming clear to anyone in the wire industry that very great care had to be taken in the whole process of making copper conductors. Not only had the smelter to deliver rod or sheet of uniformly pure copper, but the wire-drawer, himself, was obliged to pay attention to the treatment of the wire during its making. The fact that no absolute standard of conductivity nor indeed an acknowledged national standard for the conductivity of copper existed, added to the difficulties of the copper industry at this time. The problems were great and the incentives few. The orders for copper wire in its role as a conductor could be lucrative, but made only sporadic appearances in the shape of orders for submarine cables, and there was little call elsewhere.³ Though the Gutta Percha Company had, at Thomson's request, called upon the "most eminent smelters" the response had been minimal. As for the wire-drawers, their record was much the better - an improvement in length, quality and conductivity had come about. This creditable accomplishment needed however, an overnight miracle in smelting and refining technology

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1 Ibid p. 335.

2 Matthiessen A. "On the Reproduction of Electrical Standards by Chemical Means" Reports of the Committee on Electrical Standards (B.A.A.Sc.) Editor Fleming Jenkin, E. and F. N. Spon 1873 p. 18.

3 Copper was competing with Iron, (Vide p. 206, 224) and in the main Iron was becoming the preferred conductor for overland telegraphy.

to match it, and this was not to be.¹ A number of events needed to take place before these changes could be rung - a standard of pure copper needed to be established and agreed upon, and standard units of resistance and conductivity were required to replace the profusion of arbitrary standards subscribed to by various workers throughout Europe. The smelters and wire-drawers could point to the fact that any specification concerning the conductivity of a copper could be contested - much depended on what standard was used. References to "pure copper" in any specification tended to be viewed with reservation. When William Thomson suggested to the British Association in 1861² that a committee should be set up to determine the best standard of electrical resistance, part of a report by Matthiessen made it plain how matters stood:-

"It is well known how differently the so-called
"pure copper" conducts when prepared by
different experimenters".³

Siemens, Lenz, Becquerel and Matthiessen could all achieve different conductivities for "pure" copper when referred to silver as 100.⁴ The purity of the silver and the copper both came into question, and if this was unresolved so too were the practical standards (as proposed by many experimentalists) which took the form of lengths of copper wire or special alloys made into wire. Lenz had used one foot of No. 11 copper wire as a standard in 1838 but had previously utilised (in 1833) a smaller unit which was some 20 times less.⁵ Lenz appears to have chosen a unit at random and made no attempt

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- 1 The reluctance of the smelters as a body to advance their art was worth comment even at the end of the 19th century:- "The result of deeper mining, rendered possible by the use of the steam engine, was that a larger production of ore became available for the smelter, who, feeling therefore that he could buy more or less on his own terms, remained metallurgically unprogressive. In fact, it appears as though progress was even discouraged, and works exist at Swansea which attest to this day something of the heritage from the early smelters." (Brown N. - A Century of Copper - p. 2.
- 2 Encyclopaedia Britannica 13th Edition Vol. 27 p. 740 and Report of the Committee on Electrical Standards - p. 193.
- 3 Report of the Committee on Electrical Standards p. 21-22.
- 4 Ibid p. 22. It was pointed out by Bright (Submarine Telegraphs p. 216 that of all the tests on the conductivity of copper by Becquerel, Reiss, Lenz, Davy, Christie, Snow Harris, Buff, Pouillet and Arndsten, the only ones made at a uniform temperature standardised at 0°C, were those of Becquerel. Lenz and Arndsten.
- 5 Report of the Committee on Electrical Standards p. 192.

to impose it upon others. Wheatstone, in his Bakerian Lecture of 1843, stated that he employed a mass-length standard consisting of a copper wire one foot in length and weighing 100 grains. This wire was not an ordinary commercial variety ("It is intermediate to the numbers designated in commerce as 15 and 16") and was chosen for a given resistance-mass-length ratio since Wheatstone could place no confidence in the consistency of the diameter of commercial wire throughout a length, and:- "very small differences of diameter are attended with considerable differences in the resistance".¹ Approaches similar to Wheatstone's became commonplace:- "Hankel used as a unit a certain iron wire and in 1847, I. B. Cooke speaks of a length of wire of such section and conducting power as is best fitted for a standard of resistance".² A standard in German-silver wire as referred to pure silver was suggested by Buff and Horsford³ in 1847, while in 1848 Jacobi produced his standard, (a copper wire) which he proposed should be copied by others.⁴ One of the recipients, W. E. Weber, remained dissatisfied and was to propose an absolute measure that did not depend on the "resistance of an object" or the "resistivity of a substance".⁵ The idea that a basic unit of resistance could be identified was fundamental to the laws elucidated by G. S. Ohm, but his work had initially made little impression. From the period of his first papers (1825-6) he built up experimental evidence for his deductive work on electric circuits, but in 1827 he published under ill-advice his "Mathematical Theory of the Galvanic⁶ Circuit" and allowed it to be thought that his results were based only on deductive reasoning.⁷ He was well content to let it be

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- 1 Wheatstone C. "An Account of Several New Instruments and Processes for Determining the Constants of a Voltaic Circuit" Phil. Trans. CXXXIII (1843) p. 311, 312.
- 2 Fleming Jenkin "On the New Unit of Electrical Resistance" Report of the Committee on Electrical Standards" op cit p. 192. The uncertainty of the period before standardisation is summed up in W. H. Preece's "Submarine Cables" Proc. Inst. Civ. Engs. Vol. XX (1860-61) p. 38-39.
- 3 Ibid.
- 4 Ibid.
- 5 Dictionary of Scientific Biography op cit p. 206.
- 6 Shedd C. "The History of Ohm's Law" op cit p. 609.
- 7 Ibid p. 613.

thought that his work was theoretical, and without any apparent experimental basis.¹ Ohm's work was subsequently described as "a web of naked fantasies" and "the result of an incurable delusion".² His reputation was only rescued from obscurity by the tardy recognition given by Fischner, Fechner, Lenz, Jacobi, Henry and Wheatstone.³ Such recognition as was afforded to Ohm, implied acceptance of certain factors in an electric circuit; the dependence between electro-motive force and electric current, determined by a variable quality called resistance, which did depend upon "the resistivity of a substance". But though resistance standards could be exactly reproduced, their permanency was in question. Thus careful measurement might produce two copper wires with the same resistance (at a given temperature) but different dimensions; as E. Becquere had shown,⁴ and A. Matthiessen confirmed,⁵ standards based upon copper wire, alloys of various metals or columns of mercury, all had to be chosen with extreme care to eliminate problems of purity, and the variation of resistance with temperature.⁶ Thus, no two experimenters could depend upon achieving independently the same standard, if no two samples of "pure" silver or copper could be prepared with the same state of purity and the same specific conductivity. Without this, no confidence could exist over any practical standard, and in the light of the arguments concerning the long term stability of metallic resistance, temperature coefficients of one alloy as compared to a "pure" metal and the electrical permanency of standards, the idea of an absolute standard became

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- 1 I find an interesting note from E. M. Rogers (Physics for the Enquiring Mind -. Oxford University Press, 1960 p. 519) "Ohm - was the son of a locksmith, so he knew how to draw metal wires (?) of different sizes for his experiment. At that time wires were not available in stores in great variety as they are in our electrical civilisation. Ohm made his own wires and experimented with them trying different lengths - thicknesses - metals - and temperatures".
- 2 Shedd C. "The History of Ohm's Law" p. 612.
- 3 Ibid. See also Wheatstone C. "An Account of Several New Instruments -" op cit p. 304-306, and Proc. Roy. Soc. 1837-43 Vol. 4 p. 336 wherein Ohm's award of the Copley Medal is confirmed.
- 4 Becquerel E. "Sur la Conductibilité des Corps Solides et Liquides" Annales De Chem et de Physique Vol. XVII, 1846, pp 242, 290.
- 5 Report of the Committee on Electrical Standards op cit p. 17 and A. Matthiessen, C. Vogt "On the Influence of Temperature on the Conducting Powers of Alloys" Phil. Trans. 1864, Vol. CLIV p. 167.
- 6 Angstrom A. J. Phil. Mag. Vol. XXVI (1863).

the more attractive. Such a standard, based on universal physical constants, was implicit in the principle of Ohm's Law, and resolved the unit of resistance in terms of electro-mechanical equivalents. Thus, resistance could be expressed in the fundamental units of space, time and mass. The fact that electrical resistance could be described in terms of mechanical work (i.e. metre-second or foot-second)¹ was to be of supreme importance since it paved the way for J. P. Joule (1818-1889) to provide (in 1867) the mechanical equivalent of heat. Joule's deduction was achieved through experimental work entrusted to him by the British Association, and in finding the mechanical equivalent of heat from the thermal effect of electric currents, Joule was to discover that the B.A. standard Ohm was smaller than intended.² The B.A. Ohm, as tentatively established in 1867, took little heed of previous standards. The value became about 1/25 of the English "mile of No. 16 copper wire", one and a half times Jacobi's unit, approximately equal to the Siemen's mercury unit, a multiple of Wheatstone's one foot of 0.071 copper wire and fractions of the German mile of No. 8 iron wire and the French kilometre of 4 millimetre diameter iron wire.³ As for Matthiessen's 1863 standard - (a mile of copper wire 1/16 inch in diameter) the new unit was fractionally greater than 1/73rd of it.⁴

If, electrical measurement could now determine the resistance of a metal by reference to a prime standard, itself defined by absolute units, then other standards could be prepared from the best suited materials, (which would themselves be shown by experiment). Thus, two manufacturers could produce copper wire with values of resistance both referred to two separate, but electrically identical, standards of resistance. So then, if careful treatment could provide a pure metallic standard of, say, silver or copper, then relative conductivities could be absolutely determined and the quality of commercially produced ingots and wire of copper could be improved and maintained. Matthiessen, after

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- 1 At the suggestion of William Thomson, the centimetre, gram, second was adopted.
- 2 Encyclopaedia Britannica 13th Edition Vol. XV, p. 524. Joule had begun preliminary experiments as early as 1864, (See Report of the Committee on Electrical Standards op cit p. 114) a continuation of the work first published in 1843. (B.A.A.Sc, Cork).
- 3 Fleming Jenkin op cit p. 195, 193.
- 4 Report of the Committee on Electrical Standards op cit p. 112. Also Perrin op cit p. 4, who states that Matthiessen's wire was annealed and equal to 13.39 B.A. Units at 15.5°C.

devoting considerable attention to the matter, was able to produce a standard resistance wire which conformed to the constraints of permanency, accuracy and uniformity. What became known as "Matthiessen's standard" comprised a hard drawn copper wire, one metre long and one gram in weight. This was equal to 0.1469 British Association Units of resistance (later corrected to .14493 International Ohms) at 0°C.¹ Though Fitzpatrick, in 1890, was to confirm Matthiessen's results through a most careful investigation,² in later years, as the copper smelters continued to improve their techniques, it became clear that this standard could not remain. Most criticisms were objective and simply called for a review of a standard which fell down against the new electrolytically prepared copper, resulting, at times, with conductivities of greater than one hundred. Some criticism, however, voiced with overtones of arrogance, unfairly devalued Matthiessen's work, mixing the true with the false. "Matthiessen's 'standard' " it was claimed, was "based on two entirely arbitrary assumptions", (sic) and concerning these:-

"- first he assumed a certain wire to be of absolutely pure copper; and second, he chose a certain length and diameter of that wire as having unit resistance at a certain temperature. The conductivity of wire was then reckoned as 100 per cent, and samples of copper could be compared as to their conductivity -. Improved processes have now rendered this "standard" quite unreliable, by producing copper wires whose conductivity would have to be stated in figures higher than 100."³

This harsh comment was atypical, and in general comments were made without naive

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- 1 Fleming J. A. "Conduction" Encyclopaedia Britannica 10th Edition Vol. VI p. 857 - Matthiessen's original standard was set at 18°C.
- 2 Fitzpatrick T. C. "On the Specific Resistance of Copper" British Association Report (1890) Appendix 3 p. 128.
- 3 Brown N. and Turnbull C. C. "A Century of Copper. Effingham-Wilson (1899-1900) p. 81.

attacks upon Matthiessen's scientific ability. A decade earlier, for example, a more moderate position had been declared:-

"All experimenters who have tested many samples of the best commercial copper - report samples of wire giving 2 or 3% lower resistance than this standard. In fact, the wire measured by Matthiessen must have been only slightly better than the best commercial copper at present obtainable. In the year 1888-9 almost seven hundred samples of copper taken at random from the output of a large mill" gave "a number of samples giving a conductivity of 100 per cent and some which fell very low - the average of the whole was 98.98 per cent".¹

The two viewpoints provide contrasting opinions for the period 1890-1900, a period when the electrolytic process for refining copper could supplement traditional supplies of copper to those wire-drawers manufacturing electrical-conductors. A very balanced opinion is to be found in a text by Bright:-

"It frequently happens in the present day, with the various samples obtainable, that by the test calculations the wire under test gives higher conductivity than that afforded by the Standard, owing mainly to the latter not really being so pure as what we are now able to obtain commercially. (This of course points to the desirability of a fresh standard of pure copper being established). In fact electro-deposited copper wire made according to the Elmore* process has on the average a conductivity quite 2 or even 3 per cent above that of Matthiessen's standard."²

Bright was of the opinion, however, that the electro-deposition of copper had the disadvantage of slowness and costliness³ and that it was therefore not "favoured as yet for practical work on any large scale".⁴ Yet large scale operations had been set up and

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1 Perrin F. A. op cit p. 5.

2 Bright C. Submarine Cables, op cit p. 221.

3 Ibid.

4 Ibid.

* See the various patents due to A. S. Elmore.

as early as 1883; the continent produced 500 tons per annum and it was expected that the English production of electrolytic copper would exceed 3,000 tons.¹ It was costly however, and thought to be poor in mechanical qualities.² The electrolytic refining of copper was a process to become favoured by the wire-industry since it was required to answer the demands for high conductivity copper wire. The wire-drawers, in turn, made demands upon the smelters and inevitably the electrolytic process would enter into any scheme to provide very pure copper. Efforts to improve efficiency and yield in the electrolytic production of copper were to continue long into the 20th century. In the decade 1890-1900, improvements included the production of high conductivity wire by depositing electrolytic copper in the form of a spiral strip on a cylinder. This strip would be peeled off and drawn down in the usual way.³ Even this, however, was so expensive that it was worthwhile attempting to eliminate the spiral and 'grow' the copper at the draw-plate. Thus, J. W. Swan worked out a method in which copper was continuously deposited on the tail of wire passing through a draw-plate.⁴ Swan did not, however, proceed with the process. In general, quality was to be improved by careful selection of ores and greater attention to traditional refining techniques. The wire-drawers, like the smelters, were to take note of the experimental evidence presented by Thomson and Matthiessen; evidence which the wire-drawers and smelters could grasp and follow. Electrical science however, could only establish facts and set a criterion. The wire industry had to decide upon the value of attaining the requisite standard and the cost of doing so. In the last analysis, the expansion of plant for an uncertain market was a risk venture. It would be unbusinesslike and imprudent to throw all resources into developing copper wire at the expense of other profitable products, such as copper locomotive tubing, and then find that the wire benches

1 Roberts C. "Discussion on Electrical Conductors" Proc. Inst. Civ. Engs. Vol. LXXV (1883) p. 96.

2 Ibid p. 68.

3 Britannica 13th Ed. Vol. 9 p. 238.

4 Swan J. W. Jrn. Inst. Elec. Engs. Vol. XXVII, 1898, p. 16. After seeing Bolton's highly efficient wire-drawing process, Swan decided that his process was not worthwhile (Ibid p. 17). For further details on the Bolton continuous drawing process Vide supra p. 210.

were sometimes overloaded and at othertimes making the wrong product. Process flexibility was all very well but markets had to be durable and lasting, at least for a reasonable period of time, to warrant a shift in product emphasis. The signs were that copper wire demand would, as a matter of manufacturing policy, run just ahead of output. Large scale manufacture of copper wire, and special requirements as regards conductivity, were to remain subject to definite orders¹ and normal production quotas would be allowed to increase only as the (overall) average demand rose.

The face of the wire industry was to change markedly in the 50 years from the first experimental cross-channel submarine cable. The changes took many forms and affected many aspects of the industry; not least those facets dealing with the technicalities of wire-drawing, organisation, policy, labour and supply. In the final analysis, poor progress in the large scale production of high quality high conductivity copper wire for electrical conductors was a matter in which the wire-drawers could lay much blame at the feet of the smelters. Supplies of copper remained, in general, at indifferent and erratic levels of purity and for the most part the immediate realisation of a constantly stable quality of copper could not be expected. The advance of the quality of copper wire to the point where it consistently equalled or exceeded Matthiessen's standard was retarded, due to apathy and procrastination on the part of the smelters. Their excuse remained centred on the increased expertise necessary to select and process ores. Like the wire industry, the smelters looked to the value of the exercise and the associated cost. It is reasonable to conclude that in many cases the smelters felt that the criterion set by the wire-drawers was artificial and based upon a market which might, or might not, lead to better things. Capital outlay and reduced profit margins had to be minimised in what was, after all, an industry in an experimental stage! In most cases, the people foremost in making capital expenditure in electrolytic refining were the wire-drawers, themselves.²

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1 See, for example, Appendix 1 which shows the extreme variations in exports of copper wire.

2 Vide supra Ch. 9 p. 208.

CHAPTER 8

THE WIRE-DRAWERS - FROM INDUSTRIAL
REVOLUTION TO ELECTRICAL REVOLUTION

BIRMINGHAM:- THE MIDDLE YEARS

It was no accident that had made Birmingham the unrivalled centre for wire-drawing during the greater part of the 19th century. It was to be said that:-

"- "wire-drawing is peculiarly a Birmingham trade. We are, in fact, the great wire-drawers of England, and to a great extent, of Europe and America".¹

Copper and brass had formed the staple diet for the Birmingham industries since the middle 18th century, and it had been brass which had raised the importance of wire-drawing through the ever constant market for pins. But copper wire like iron wire, had many uses. The Birmingham plate-makers' shops, and the traditional craft of the brazier found uses for copper wire both special and general, as did many other trades depending on copper wire:- Calico printing blocks, music type,² ships sheathing, nail making, bell-hanging, lightning conductors and many others flourished, floundered or in some cases died^{*} but nevertheless, maintained the importance of copper wire.

Birmingham had but eight wire-drawers in the Town in 1777,³ a number quite sufficient, it seems, to meet the needs of the local industries. For that period at least, the same could be said of Wolverhampton, Sheffield, Walsall and York.⁴ However, as the Birmingham trades responded to increased demands, the capacity of the Birmingham

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- 1 From the Birmingham Daily Post. March 29th 1866, reprinted in Timmins S. The Resources, Products and Industrial History of Birmingham and the Midland Hardware District. Robert Hardwicke 1866 p. 589.
 - 2 Cyclopaedia of Useful Arts and Manufactures op cit p. 910.
 - 3 Cook M. "The Development of the Non-Ferrous Metal Industries in Birmingham" Metal Industry Vol. 48 (1936) p. 488.
 - 4 By the middle 1900's the wire-drawing industries became centred chiefly at Warrington, Manchester, Halifax, Sheffield and South Wales (Timmins op cit p. 595).
- ^{*} Button making, for example, was a Birmingham trade from the 1680's (Hamilton op cit p. 131) and the supply of shank wire for buttons represented a good trade. One metal for shank wire was known as red metal; copper with a small addition of zinc (Thorpe E. Dictionary of Applied Chemistry Longmans, Green 1927 Vol. VII p. 585) The demise of the hand-made button due to the introduction of machine made buttons in the 1860's lost to Birmingham a good market in wire and buttons. In some other areas the effect was catastrophic - witness the forced emigration of button makers from Shaftsbury in Dorset. (Shaftsbury Museum, Dorset).

wire-drawers enlarged to answer the needs of the expanding Birmingham manufactories. A seemingly unquenchable market, the supply of brass and copper rod and wire to the African trading posts,¹ had become the province of the Birmingham rolling and wire mills. It was not uncommon for Birmingham wire mills in the middle 19th century to advertise "Rings For The African Market",² or "Copper Guinea Rods".³ These were commodities which could be supplied by almost any wire or rolling mill in Birmingham, a firm traditional market, African trade articles required little additional labour after drawing or rolling. Hanks (rings or coils of wire in long lengths) in the natives preferred gauge of No. 4 or 5 B.W.G.⁴ were shipped to Africa in large amounts.⁵ By 1860 however, copper had begun to lose its position as the most desirable material for the native artisan. The "Katinda" or coil bracelet was to be seen more and more in brass since cost had excluded copper (which at times could be priced at more than the "one dollar" (4s. 2d.) charged for brass). Nevertheless, copper wire was greatly valued and often in evidence:-

"The costume worn by the Wanyamwezi are brass bangles, massive brass rings - the waist is girt by a coil or wire - and the ankles are covered with a profusion of iron-bells, thin rings of brass and copper wire".⁶

Descriptions of the adornments used by African natives are seldom without reference to "solid rings of copper" or "bangles of copper" and indeed copper chains,⁷ all of which came by courtesy of the Birmingham wire-drawers with some assistance from the native metal-worker.

Though the trade in copper wire for the needs of the African market gave work to a high proportion of the wire-drawers throughout England in the early 19th century, it was by then a market sought by too many. All other outlets for wire had to be viewed with

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1 Vide infra Ch. 4 p. 105.

2 Deritend Rolling Mills - found in The Visitors Handbook Through the Manufactories of Birmingham Cornish - Birmingham 1852.

3 Birmingham Battery and Metal Company - Ibid.

4 Timmins S. op cit p. 319.

5 Vide Ch. 3 p. 99.

6 Burton's "Travels" from Timmins op cit p. 320.

7 Livingstone on the sister of "Sesheke" - found in Timmins op cit p. 320. See also Ch. 2 p. 88 .

optimism, so as not to risk the chance of unprofitable wire mills with unmanned draw benches. A wire mill could cater for many types of wire most easily,¹ and it was a feature of mid 19th century mills that all types of wire could be had. Though copper was to take on a special role with the advent of submarine telegraphy (and later telephony and power transmission) at the outset, the drawing of copper wire was hardly distinguishable from that of any other metal. Thus, the peculiar problems of ensuring a high-conductivity copper wire of superior mechanical (tensile) properties were not generally in evidence in the middle of the century. The 1850 s, the dawn of the era of submarine telegraphy, saw six major wire mills in Birmingham advertising a complete range of wire, copper wire taking only a modest place in the lists.²

Of the major Birmingham companies for this period, pride of place must go to Thomas Bolton & Sons. This firm was to stand as the first to grapple with the needs of the submarine telegraph;^{*} needs, which in its infancy called upon Thomas Boltons' to supply the copper wire for the fated experimental channel cable of 1850, the successful cable of 1851³ and led to the historic attempts to achieve Trans-Atlantic telegraphy in 1857/58 and 1865/66. The company still survives to this day and can trace their origin to an earlier Thomas Bolton (1790-1853) who had inherited or acquired a Birmingham founded business from his father, Richard Bolton.⁴ The premises for the business had begun in 1783 as a small dwelling-house come workshop, typical of many such enterprises before the 1840 s.⁵ The first act of expansion however, was in 1825 when Thomas Bolton Snr., built works at Broad Street, Birmingham. In March of 1852, the old works of the Cheadle Brass and Copper Company⁶ at Oakmoor was put up for sale and Thomas

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1 Paul Moore & Company (Great Lister Street, Birmingham) supplied brass, copper and iron wire. A Everitt & Son (Birmingham) made brass and copper wire and brass and copper tubing. Nicklin & Smith (Bradford Street, Birmingham) drew fine copper and brass wire and manufactured brass and copper wire net. (Catalogue Of The Great Exhibition of 1851, Spicer, London 1851 Vol. II, p. 624, 632 and 636).

2 The Visitors Handbook - op cit.

3 Part of this cable is to be seen at the works of Thomas Bolton & Sons, Froghall, Stoke-on-Trent.

4 "Thomas Bolton 1858-1937" The Bulletin of British Non-Ferrous Metals Research Association Vol. 97 (April 1937) p. 3.

5 Timmins S. op cit p. 359.

6 Vide infra Ch. 3 p. 99.

* It may be remarked that Thomas Bolton's original prosperity was based primarily upon the manufacture of sheet brass, German Silver and copper; round and shaped brass, brass and copper tubing; locomotive and mandrill drawn tubing, brass solder and brass and copper wire. (See Cat. Grt. Exhib. Vol. II p. 636).

Bolton sent his two sons, Alfred (1827-1901) and Francis (1828-1909) to bid for the works and its contents.¹ A low offer was accepted, and by 1853 the firm of Thomas Bolton became Thomas Bolton and Sons when A. S. Bolton and F. S. Bolton were taken into partnership. When, at the end of 1853 Thomas Bolton Snr. died, business was carried on by A. S. Bolton chiefly in Staffordshire, and F. S. Bolton in Birmingham.² Throughout most of the 19th century the Company's works were to centre mainly on Oakmoor and Birmingham though some operatives were to be established at Widness (1881) while the present Froghall works were erected in 1890 by A. S. Bolton's son, Thomas (1858-1937).³ As pre-eminent in the field of drawing copper for submarine telegraphy from the 1850 s, the company was to take a special interest in the art of drawing wire for telegraphic and electrical (power) purposes. Initially, however, the company made do with traditional equipment⁴ for drawing the long lengths required of them by the submarine telegraph companies. Nonetheless, even with fairly primitive draw benches the needs of the 1865 cable were successfully met - 690,000lbs (308 tons) of copper was drawn into 16,100 miles of No. 18 B.W.G. wire.⁵ At this time, the copper was bought in as rolled copper strip 3/8 or 1/2 inch in thickness and again rolled to approach in thickness, the required wire gauge. The strip would be slit by revolving steel cutters which would then form a square section "wire". The section was then formed into round wire by a succession of drawing processes utilising the standard draw plate and powered drum.⁶ This method - unsatisfactory for all the requirements of telegraphy and electrical conductors - was to be an area first improved upon by A. S. Bolton⁷ (in the form of a

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- 1 Private correspondence with Thomas Bolton and Sons.
- 2 Ibid. See also The Bulletin of British Non-Ferrous Metals Research Association op cit p. 3.
- 3 The Bulletin of British Non-Ferrous Metals Research Association op cit p. 4.
- 4 Vide infra Chapter 1 p. 69. See also the comments by Willoughby Smith on the poor quality of the copper wire produced by traditional methods. Ch. 7 p. 169, 170.
- 5 Timmins S. op cit p. 316 - Some assistance in meeting this enormous demand was given by another Birmingham company, Messrs. Wilkes and Sons. Ibid.
- 6 Vide infra Chapter 1 p. 69. See also Ch. 9 p. 210.
- 7 The Bolton Company's traditional resourcefulness enabled them to proceed directly if necessary, from cast ingots of copper (wire bars) through flattening (rolling) into strips, slitting into square sections and then rolling through grooved rollers in preparation for the draw benches. This however, was a situation first to be realised in 1883; a complete processing sequence which evolved from the 1850 s. See A. S. Bolton "Electrical Conductors" Proc. Inst. Civ. Engs. LXXV 1883 p. 102, also Cat. Grt. Exhib. Vol. II p. 636.

patent for compound wire) in 1863¹ and later in 1886/7 when he, and his son Thomas, perfected a method of continuous wire-drawing.² Up to this time however, wire-drawing had remained the province of a skilled man using a specialised machine with a productivity limited by the quality of the equipment, and the skills of the operator. For all ordinary purposes however, this was sufficient. Amongst those companies drawing wire for telegraphic purposes, copper and iron could be drawn in gauges and lengths not unfamiliar to those demands of spring-wire & wire ropes, card wire, binding wire, brush wire or bell wire. Commonly, wire-drawers catered for all, and only exceptionally, as in the case of Boltons' and the needs of submarine telegraphs, were their manufacturing resources stretched. It took 16 years (1850-1866) for Boltons to turn their copper wire from a material of irregular gauge ("with parts soft and rotten, hard and brittle") to a consistent product of good quality and high conductivity.

A typical wire mill in Birmingham about 1853 is that of Samuel Walker Junior³ at the Deritend Rolling and Wire Mills.⁴ His advertisements describe the firm as a "Contractor to the Board of Ordnance", and manufacturers of improved brass tubes for "Locomotive Steam Engines". Only after this has been impressed upon the reader does the advertised list of wares mention brass and copper wire as the next product of importance. This is then followed by some 14 products, processes or services on offer from the Mill - rods and tubing of Brass, Copper and Zinc - the gilding of wires, Ingot Brass, German Silver dipping, Tin pipes etc.⁵ This remarkable range is made the more so, when it is considered that the complete operation was carried out in one large workshop, 70 feet by 100 feet in floor area and some 35 feet high.⁶ As seen in Plate 49 the work area was well laid out, the ten draw benches and the annealing "muffle" for copper ware being located in close proximity to one another and well removed from the gears and equipment of the

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- 1 Vide supra Ch. 10 p. 222 . A composite wire attempting to combine the strength of steel and the conductivity of copper.
- 2 British Patent No. 8133. For further reference to this see Ch. 9 p. 210 .
- 3 A patentee (1851) for "metallic tubes" .
- 4 Fazeley Street, Birmingham.
- 5 The Visitors Handbook -. op cit p. 149.
- 6 Ibid. - Inset affixed to cover page.

rollers. Interestingly, the firm appears to have had no interest in manufacturing wire specifically for the telegraph. The Cornforth Brothers, who had mills in Dartmouth Street, appear to be the one principal Birmingham wire mill at this time manufacturing "Electric Telegraph" wire.¹ In this instance, the wire appears to have been of galvanised iron. Other firms such as the Birmingham Battery and Metal Company (Digbeth works),² Paul Moore and Company (Great Lister Street and Park Mill)³ and Hughes and Evans (High Street Deritend Birmingham)⁴ all manufactured a wide variety of goods (similar to that of Samuel Walker's which included copper wire. The Birmingham Battery and Metal Company laid emphasis upon its manufacture of copper wire, as did Hughes and Evans who referred to theirs as "fine". Only Messrs. Cornforth, S. Walker Jnr., and the firm of R. W. Winfield were acknowledged as primarily wire-drawers whilst the Mills of Hughes and Evans etc., were treated as Rolling Mills. Indeed, the Birmingham Battery and Metal Company cast "House and other Bells"⁵ in keeping with the manufacture of copper bell-wire. The ability to produce wire in shapes other than round (generally the task of the draw-bench) enabled some firms to extend their markets further. A company with rolling and slitting facilities could find a good outlet in square copper wire stretchers⁶ used in umbrella and parasol manufacture and although by the 1850 s this was a declining trade, it had initially found more than modest employment for the rolling mills.

Of other aspects of the Birmingham wire-drawers, it may be remarked that whereas the 1780 s had passed with no more than eight wire-drawers recorded as being in operation by 1841 some 90⁷ hands were engaged in the trade and by 1866 there were nearly 600.⁸ No woman or boys are recorded as being employed in the manufacture of wire and in general

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- 1 The Visitors Handbook - op cit p. 81. This firm was originally John Cornforth of Berkeley Street Wire Mills, Birmingham. From 1852 the firm became Cornforth Brothers upon the death of John Cornforth. See Cat. Grt. Exhib. Vol. II p. 630.
- 2 The Visitors Handbook - op cit p. 92.
- 3 Ibid. p. 79. Vide infra Chapter 1 p. 75 - for comment on Moore's draw plate.
- 4 Ibid. p. 108.
- 5 Ibid. p. 92.
- 6 Timmins S. op cit p. 667.
- 7 Timmins S. op cit p. 594.
- 8 Ibid.

conditions of work were high.¹ It was said:-

"- change for the better is recognisable in establishments for the production of - wire. For the creechy rolls, the primitive draw-benches, and clattering wire blocks - draw-benches with admirably fitting trains of wheels and chains of great strength, and wire-drawing blocks well fitted, revolving truly and silently, have taken the place of their imperfectly constructed representatives in a preceeding generation -. The buildings are large, ample roofed and of course on a ground floor."²

Wire-drawers, themselves, however were viewed with some reserve:- "As a body they do not take high rank in the social scale" but nonetheless possessed perhaps "as many noble exceptions as others".³ They would be happier and "fulfilling their part - as creditably as they are certainly qualified to do - when more fully alive to the advantages of temperance and providence."⁴

A wire-drawer could earn on average 35 shillings per week, exceptionally 50 to 65 shillings in 1866. The average wage for a workman in the brass and copper industries in Birmingham at this time averaged 18 shillings per week⁵ which is evidence of the prosperity the wire-drawers as a company enjoyed, and why temperance was not something that would necessarily allow them merely to retain enough wages for the necessities of life. So lucrative was the trade that in 1839, those of an appropriate age were urged to find

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1 Ibid.

2 Timmins S. op cit p. 360.

3 These men were skilled and ranks above mere labourers. The activities of one, Francis Deakin, cannot be left with comment. According to Prosser (op cit p. 132) the whole Deakin family was inventive. Francis Deakin who was drawing wire at the Deritend Mills in 1812 patented "sheaths of, and cases for knives" (Prosser op cit p. 200). In 1822, Francis Deakin described himself as a "sword maker and wire-drawer" in his patent for "Holster cases, cartouch boxes etc." (Ibid p. 202). In 1823 he had become a "sword maker" but in a patent for that year, his invention relates to "stringing pianofortes" (Ibid). In the same year another patent is taken out for "umbrella furniture" and here Deakin describes himself as a "wire worker", (Ibid). (It seems unlikely that this is the work of two Deakins' as Prosser would prefer to believe (Ibid p. 131). He appears to have confused the issue through a misprint in his patent lists. He refers to the 1811 patent of William Deakin (Ibid p. 166) but ascribes this to Francis Deakin in his 1812 patent lists (Ibid p. 200)).

4 Timmins S. op cit p. 595.

5 Ibid p. 594, 361.

employment in wire-drawing since:-

"Wire-drawing in all its branches is profitable to the Master and Workman; it is a good business, being a trade that is not exposed to the weather; that can be carried on at all seasons of the year; and by which the workman may earn from one guinea to double that sum in a week".¹

A seven year apprenticeship was not unusual² and the tradesmen found protection and representation in their own Guild of Tin-Plate Workers and Wire-Drawers.³

It is interesting that the industrial organisation of the Birmingham wire trade and the social position and affluence of the wire-drawers points to a level of confidence and stability throughout this particular specialisation, apparently based upon high expectations of trade and profit. Wire-drawing was not at this time, nor had it ever been, a high dependence industry relying upon one market for a specialised commodity. Wire of many kinds were made in the wire mills and allied with the production of a staple commodity, the wire-drawer was in no way reluctant to provide additional services. Hence the average wire mill supplied a broad market where minor fluctuations were eclipsed by peak demands from other areas. Traditional trades and new applications caused seasonal changes in the wire-drawers' operations, but the general trend was that of a stable production quota. The wire-drawer, rightly, had high expectations of a secure and prosperous future - his trade could do nought but flourish as industry itself expanded. However, as will be related, some of the wire-drawers' affluence was borne of fraudulent practices!

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- 1 The Young Tradesman - or Book of English Trades. Whitaker - London 1839 p. 437 (B.M. 8233.aa.78).
- 2 Hamilton H. op cit p. 322. Ibid.
- 3 Berry C. W. The Worshipful Company of Tin-Plate Workers Alias Wire-Workers. London 1926 (B.M. 08245.h.57).

WIRE GAUGES

No other aspect of wire-drawing was more surrounded with confusion than that of the early wire gauges. The mere act of designating a wire diameter by some number, or indeed, being able to state the distance in definite units or part of a unit length, appears to have been licence for early wire-drawers to take it upon themselves to set up private gauge standards without regard for others. The first gauge of any note is attributed to Lewis (Philosophical Commerce of Art - 1735)¹ and utilised a brass plate with step-like notches so as to compare the wire diameter against a standard dimension. According to Hughes, (the English Wire Gauge - London 1879) no wire gauge prior to 1842 contained more than 26 sizes.² By 1884, however, it was to be said that though this might be the case "The different wire gauges in use might be counted by hundreds".³ Hughes was to display no less than fifty-five different gauges in 1879, forty-five of which were for wire sizes consistent with wire on sale in the United Kingdom.⁴ Though the Americans, who relied on the Birmingham (Old English) wire gauge, began to rationalise their system in the 1850's by introducing a new gauge caliper, it was not until 1857 that drastic action was taken to curtail the proliferation of gauges.⁵ During that year, The American Association of Brass Wire and Sheet Manufacturers ordered from the firm of Brown and Sharpe a number of "V" gauges numbered according to the Birmingham system, and this was expected to be adopted as the universal American standard.⁶ However, lack of uniformity in the sizes of wire contained within the Birmingham Wire Gauge resulted in a new standard using increments of gauge, based upon a geometric progression. This method was well received and was finally adopted. Only a few attempts were later made to revise the standard, most notably

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- 1 Encyclopaedia Britannica op cit Vol. 28 p. 739. See also Bucknall-Smith op cit p. 12
- 2 Britannica Ibid.
- 3 Report of the Board of Trade (1884) to be found in Britannica (Ibid).
- 4 Bucknall-Smith J. op cit p. 125. "In the same town, some use Stubs, some the Warrington, some the Lancashire, some the Yorkshire, some the Birmingham, some the iron wire gauge, all maintaining the Gauge in their own possession to be the correct one". (Britannica op cit p. 739).
- 5 Perrin F. A. op cit p. 77.
- 6 Ibid.

by the Edison Company who preferred gauge numbers which represented even thousands of circular millimeters.¹ The sole result of this was that it hindered the sales of Edison made conductors.² The only other gauge to find acceptance in the United States was the Roebling-Washburn standard which was still recognised at the beginning of the 20th century.

The first act of unifying gauges in England had taken place with the introduction of the Birmingham Wire Gauge,⁴ a standard upheld in the Birmingham district originally, but even in that locality prone to abuse. In other areas, notably Lancashire, alternative gauges found preference. Stubs of Warrington commenced by gauging his wire in "mills" in 1843⁵ and this standard then went into competition with the gauges of Johnson, Whitecross, Rylance, Yorkshires', Nettlefold, "rogue" Birmingham and Lancashire gauges and a good 35 more!⁶ Stubs' gauge did at least have a firm dimensional foundation since it used a metric base and it was due to this that J. Whitworth adopted it in 1857.⁷ The inconsistency of the English gauges was a subject taken up by J. Latimer-Clarke in 1867. For three successive years (from 1867-1870) he made attempts to have a British Association committee formed to look into the question of gauges but eventually retired from the effort in this quarter, without success.⁸ He did however, formulate a rationalised gauge based on the "mil" and it was later to be sanctioned by the British Board of Trade when it made its appearance as the

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1 Ibid.

2 Ibid.

3 Ibid.

4 Exactly when this happened however, is not known.

5 Bucknall-Smith J. op cit p. 125.

6 Ibid p. 126. Of the thirty-five the following may be included, Wynne's, Cocker's, Walker's, Watkins's and Trotter's. (See article On The Birmingham Wire Gauge Jrn. Soc. Tele. Engs. Vol. 8 1879 pp 476, 504).

7 Bucknall-Smith J. op cit p. 125. Also J.H.C. Accounts 1881 (370-2) XXXVII and 1882 (307-3) XXVII.

8 Latimer-Clarke J. Reports of Brit. Assoc. Ad. Sc., Dundee 1867 p. 153, Norwich 1868 p. 189, Exeter 1869 p. 209. The 1867 report is reprinted in Jrn. Soc. Tele. En Vol. 7, 1878 p. 332-336, as is the 1869 report p. 336, 344.

Imperial Wire Gauge.¹ In 1872, in support of Latimer-Clarke, W. H. Preece and H. Mallock proposed a new telegraph wire gauge based on a mass-length standard. Referring to Latimer-Clarke's comments on the disorganisation in wire gauges, Preece and Mallock pointed out that non-standardisation could at least be evaded, and become less problematic, when purchasing or ordering copper wire:-

"And yet the practice at present is invariably to specify and to purchase copper wire for cables by weight, and the application of the Birmingham Wire gauge to the dimensions of copper wire is rapidly falling into disuse and copper wire is either designated by its weight per knot or by its diameter".²

Despite this however, much was to be lost through the disorganisation in wire gauges. Hughes recounts the case of an American order which was for copper wire of No. 32 Warrington gauge, but being received by a Birmingham wire-drawer, the wire was despatched as No. 32 B.W.G. At that time, No. 32 Warrington gauge was No. 36 B.W.G. and resulted in a price difference of £29 per ton less than expected.³ Continued instances of this nature unsettled the English wire-makers. Especially since the problem was diverting American orders to the Continent where the French and German wire-drawers had long established a national standard wire gauge based on the millimeter. In 1882-3, the Wire Manufacturers Association agreed to the inauguration of Latimer-Clarke's Imperial Wire Gauge* as supported by the Board of Trade, and in March 1884 the new uniform gauge became law.⁴ Though obsolete gauges were still to be quoted after this time much had been improved. The principal influence in the instigation of the new gauge, J. Latimer-Clarke, finally realised victory, but not by way of a British Association committee as he had anticipated. The principal lobby in this respect was to lay with the

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1 Encyclopaedia Britannica 13th Ed. op cit p. 739 and J.H.C. Vol. XI (1878/9) p. 193.

2 Preece W. H., Mallock H. "On A New Telegraph Wire Gauge" Jrn. Soc. Tele. Engs Vol. I, 1872/3 p. 81.

3 Bucknall-Smith J. op cit p. 127 - after Hughes. See also Jrn. Soc. Tele. Engs. Vol. 8 1879 p. 482 where it is recorded as No. 36 Stubs (Warrington) gauge being equal to No. 44 B.W.G!

4 Bucknall-Smith J. op cit p. 129. See also J.H.C. Accounts 1884 (322) XXVII.

* Since the Board of Trade gauges had originally appeared as the result of an offer by Sir. J. Whitworth to provide a set of standard gauges, some credit should be accorded to him. See J.H.C. 1881 (370) XXXVII.

authority of the Society of Telegraph Engineers which published an exhaustive report on the subject of gauges in 1879.¹ The report followed the work of an investigative committee (which did not include J. Latimer-Clarke) set up to review the problem. This report, and the acceptance of the Manufacturers Association² in conjunction with the Board of Trade, removed most of the doubt surrounding wire gauges, a doubt well expressed in the following extract:-

"When competition is keen, wire is commonly drawn by one gauge and sold by another; half sizes and quarter sizes are in constant use among the dealers, the wire being sold as whole sizes. Sometimes 4 or 5 different gauge plates have been made by one maker - some by which the workmen are paid and others by which the wire is sold - The whole system is in confusion and lends itself to those who desire to use fraudulent practices".³

Such protests were not aimed solely at the owners of the wire mills. Cries against fraudulent practices inevitably brought the trade of wire-drawing into disrepute. The workers themselves, employed to exercise their skill in drawing wire, and enjoying substantial remuneration for it, were no less skilful in recognising a threat to their future prosperity. Hence, they as a body, resisted any change in the disorganised, but familiar, gauges. As to the question of reputation, allegations of short orders and overcharging appeared to have little affect when balanced against the prospect of lower wages.

Nevertheless, change did come from both legislation and through consumers who, having tasted deceit once, forswore returning to the same mill a second time. In the end, even a market so large as wire turned away from sharp practice and with the introduction of a common standard gauge the wire industry and its customers found renewed trust and confidence without loss of business.

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- 1 Committee Report of the Society of Telegraph Engineers - Birmingham Wire Gauge Jrn. Soc. Tele. Engs. Vol. 8, 1879 p. 481.
- 2 Vide supra Ch. 11 p. 243.
- 3 Ibid. p. 481. A previous report by Preece and Mallock (Jrn. Soc. Tele. Engs. Vol. 1 1872-3 p. 79) had quoted Latimer-Clarke's efforts at the British Association and proposed the adoption of a mass-length gauge.

CHAPTER 9

REVERSALS & GAINS -

NEW METHODS AND IMPROVED MARKETS

Between 1850 and 1875¹ copper wire had experienced few prospects and found little favour in overland telegraph work. The telegraph systems of many countries had forged ahead leaving a network of iron wire and little or no copper was to be seen in overhead lines. What wire was used could be found mainly in underground or submarine cables; where tensile strength was a property not greatly valued. Iron was cheap and it was strong. When asked by Colonel T. P. Shaffner in 1855, "What kind of (telegraph) wire do you use?" Charles Bright replied "Galvanised iron wire No. 8!"² This answer was based on Bright's contention that copper wire, as it was at this time "showed a considerable difference in conducting power"³ and required, for a line longer than 100 miles a gauge of not less than No. 16 B.W.G. (.065 inches). Poor tensile strength and a variable standard of conductivity were reasons enough for rejecting copper as a telegraph conductor, but in 1860 an old fear concerning its use was to be raised. Copper wire, it was to be remarked:-

"- was originally used for land telegraphs but its want of tensile strength and especially its value to marauders renders it inapplicable for open-air lines."⁴

Robert Sabine was to voice a like objection in 1867:-

"- the danger to which a copper line is constantly exposed of being cut and the wire stolen is an argument against it."⁵

In the neighbourhood of smoky towns nevertheless, iron wire was liable to rapid decay.

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- 1 The Austrian telegraph employed copper wire from 1846 to 1855; a trial of iron wire in 1852 proved unsatisfactory because of defective joints. However, as more lines were needed and the number of crossings and poles increased, copper became impracticable because of its cost and low tensile strength. Iron was exclusively used from 1856. Mileteer H. "Electrical Conductors" op cit p. 117.
- 2 Bright E. B. The Life Story of Sir C. T. Bright -. Constable 1899 (2 Vols) Vol. 1 p. 418, 428. This was one answer to a series of questions put by Shaffner to Bright in preparation of Shaffner's book 'The Telegraph Manual'. (op cit).
- 3 Ibid p. 439 (Vol. 1).
- 4 Joint Committee into the Construction of Submarine Cables op cit p. xiv.
- 5 Sabine R. The Electric Telegraph. Virtue Brothers 1867 p. 195 - This had in fact happened to the Paris-Rouen line in 1848 in the midst of revolution! (On Electrical Conductors Proc. Inst. Civ. Engs. LXXV 1883 p. 122). See also p. 223 footnote 1.

In areas around London, Manchester and other northern towns, smoke laden atmospheres could erode an iron line fairly quickly.¹ The same was true of sea air, but in all cases galvanised (zinc dipped) wire - or as a last resort - copper^{*} could be used in very hostile environments. For copper wire to compete, a number of factors needed to be attended to. The conductivity of copper wire had to be improved to a consistently high level and some way had to be found to maintain high conductivity simultaneously with an improvement in tensile strength. If this could be done, and manufacturing techniques improved, a better quality and cheaper product² could be made available and this might displace iron and steel telegraph lines. But the incentives for these improvements were not great, since iron and steel were well established and were products amongst a range of wires to be had from most wire-drawers. They would supply copper wire as easily as iron, but would never jeopardise the position by contesting the needs of a customer. But for the appearance of alternative demands on the wire industry, progress in copper wire (except in the area of submarine telegraphy) would have been limited. A number of indirectly related factors helped to continue improvements and change the emphasis on iron wire, and these lay in the techniques of electro-deposition, continuous drawing, and in the new technologies of telephony and power generation.

Electro-deposition (electro-refining) of copper had for a time been the domain of the electro-platers in gold and silver. In 1852, Birmingham could boast of 13 or more such firms³ who were engaged in this practice. One of these was the firm of Elkington Mason and Company. It was James R. Elkington (1801-1865) who had patented⁴ in November of 1865, a method of refining copper by using "blister" copper (raw copper pigs) as the positive electrode in an electrolytic cell - a similar patent quickly followed through the

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- 1 Preece W. H. "The Progress of Telegraphy" Proc. Inst. Civ. Engs. LXXVI 1883 p. 6. See also Shaffner (op cit p. 515) who cites Pittsburg as experiencing the same problem.
- 2 "Mechanical strength and price seem to have been the only considerations that governed the choice of conductor in the early days" ! (Preece "Electrical Conductors op cit p. 64).
- 3 Visitors Handbook. op cit p. vii.
- 4 British Patent No. 2838 November 3rd 1865.
- * For comment on this, see Preece "Electrical Conductors" op cit p. 66 and Steinheil op cit p. 53.

work of C. W. Harrison (May 1866) but J. R. Elkington carried out the first commercial production of electrolytic refined copper at Pembrey near Swansea in 1869.¹ Elkington was one of the earliest to use a dynamo² to supply power for the electrolytic cells and very quickly electrolytic refineries were set up by various companies, both smelters and wire-drawers. Vivian and Sons (Hafod Works, Swansea), Williams Foster (Morfa Works, Swansea) and Thomas Bolton and Sons (Oakmoor) were all companies that allocated works divisions to electrolytic refining.³ All these companies had been in existence at the beginning of the 19th century and all still traded at the end of the century (except for Elkington Mason who were to be acquired by Elliots Metal Company of Selly Oak, Birmingham).⁴

Along with the careful choice of ores, methods such as electro-refining, and the replacement for old extraction techniques by multi-hearth roasting furnaces (and side-blow converters in imitation of the Bessemer furnace), could provide by the 1880 s a very high grade copper. "Blister" copper⁵ - which came nominally as 98.5% pure from the converter - could be re-refined electrolytically, but this particular process was eventually to go over to using "tough pitch"⁶ (a tough red homogeneous copper) which could be as high as 99.5% pure.⁷ For most electrical applications this level of purity was adequate and the additional £2 - £3 per ton in cost for "tough pitch" no great disadvantage.⁸ Higher

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- 1 Cook M. op cit p. 489.
- 2 According to Prosser (op cit p. 116) however, Woolwich, Percy and Paine had utilised a "magneto-electric" machine for electro-deposition as early as 1845.
- 3 Alexander W. O. "A Brief Review of the Development of the Copper, Zinc and Brass Industries in Great Britain from AD 1500 - 1900" Murex Review No. 15 Vol. 1 (1955) p. 419 et seq.
- 4 Ibid.
- 5 A technique, first tried by William Gossage, William Keets and John Holloway in the period 1855-65. See Schofield A Remarkable Century in the British Copper Industry op cit p. 27.
- 6 Derry and Williams op cit p. 493.
- 7 Brown N. and Turnbull C. A Century of Copper -. op cit p. 2.
- 8 Ibid.

purities for special purposes, such as experimental work could be had from a few companies that provided a service in this respect.¹ "Tough pitch" copper could be electrolytically refined into a state of very high purity and as electrolytic techniques advanced wire could be produced which at times exceeded Matthiessen's standard. As the quality of copper was improved it also became possible for the wire-drawers to meet the electrical requirements demanded for copper conductors. It was generally true of any firm of wire-drawers that they would be prepared to spend some time and money in improving their products, especially if - as in the case of iron wire - they might take an order that would otherwise have gone to a rival. Some competition was stimulated by what were called "scientific demands" (the demand for improved conductivity) and the wire industry on at least one occasion was praised for its ability "to follow scientific demands" to a "high degree".² In essence, however, the wire industry bowed to the call of its markets and it was in this area that "scientific demands" were really felt. Telegraphy called for cheapness, uniformity and electrical and mechanical integrity for its conductors. Cheap copper wire made it attractive to the telegraph companies and of little value to thieves. This, allied with the appropriate electrical and mechanical characteristics meant that it could displace iron wire resisting both the elements and the chances of being stolen. These were qualities however, that had to be paid for by the wire industry in development costs. Fortunately, much of this cost was to be met before the huge demands for copper wire began in the late 19th century with the appearance of high speed telegraphy, telephony and power transmission. For copper wire, the first phase of its use as a communications conductor had ceased with it being displaced by iron and steel for overland telegraph lines in the 1850s. A second phase had then occurred with the specialised use of copper wire in submarine cables and underground telegraph links.

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- 1 Thomas Boltons' at Oakmoor, were to be of help to W. H. Preece (Vide Ch. 10 p. 225) while other companies, receptive to the needs of individual experimenters, were Messrs. Smith of Halifax (wire drawing) and Washburn and Moen (Vide Ch. 11 p. 233). The firm of Johnson and Matthey had the curious honour of serving William Thomson (1857), Matthiessen (1862) and Fitzpatrick (1890). Though primarily suppliers of wire and coils formed from noble metals, Johnson and Matthey supplied all three of the experimentalists with especially drawn wires made of high purity metals, and produced alloys of copper to order.
- 2 Werner Siemens "Correspondence on Electrical Conductors" Proc. Inst. Civ. Engs. LXXV (1883) p. 120.

The third phase of its development began with high speed telegraphy in the late 1870 s and to prepare for this, work was to be done in improving wire-drawing techniques. The cost, however, was to be great and specialised methods and specialised companies developed where old established firms were disinclined or unable to meet the challenge. One company, who quite early allocated funds to answer the needs of telegraphy, was that of Washburn and Company of Worcester, Massachusetts.¹ This particular firm (later to become Washburn and Moen) was held in high regard by the American telegraph engineer T. P. Shaffner. In recording his visits to the works of Washburns' (about 1852) Shaffner recounts both his, and the company's endeavours to improve the quality of wire for "the especial wants of the telegraph".² Improvements, and a consistency in quality were arrived at "regardless of expense".³ The same enterprising spirit, but perhaps not quite the same attitude to capital expenditure, was found at Thomas Bolton and Sons. In this case, however, the company's main interest was in the high speed production of wire, and it was here that their contribution to manufacturing techniques was most important. In the area of wire-drawing methods, Bolton, and a number of other firms, were to see an opportunity of eliminating wasteful, slow and generally outdated wire-drawing methods and through this improved efficiency generate new markets through improved products.

Improvements in wire-drawing applied as much to iron and steel as to copper and in general, advances in iron wire making stimulated better methods in copper wire-making. The converse however, was not often true. The outstanding exception to this was the firm of Thomas Boltons'. Here, the primary interest was the production of copper wire and the emphasis in this direction was displayed in the development of continuous wire-drawing machinery. (The patentees, A. S. & T. Bolton described themselves as "Copper and Brass Manufacturers").⁴ The new wire-drawing machinery, though not entirely new in its aim (the successive reduction of copper wire in one continuous process) was nonetheless the most compact and practical up to this time. The elegant principle of the method was to

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1 Shaffner T. P. The Telegraph Manual. op cit p. 519.

2 Ibid. Vide supra also Ch.10 p. 234.

3 Ibid.

4 British Patent No. 8133 filed March 5th 1888. Vide infra Ch. 8 p. 196.

continuously reduce (15 to 1)¹ the wire through successive draw-plates (dies) and to compensate for the additional length of wire between dies by effecting automatic regulation through the 'slip' of the wire around a revolving drum.² Up to 1888, when this machine appeared, wire-drawing had remained very traditional in its methods and no great changes had been made from the beginning of the century.³ Small improvements had appeared - alternatives and variations had been proposed - but little more. Bell, in 1815, had made wire by rolling sheet copper between fluted rolls and had then broken away the indented wires by slitting or by means of specially designed grooved rollers.⁴ This method was novel, but like subsequent inventions (e.g. such as Todd's - B.P. No. 4257 of 1818 - and Church's - B.P. No. 4258 of 1818) it relied on rollers. Reid's patent of 1846 (B.P. No. 11,430) has some significance in that it improved the length to which iron wire might be made by joining the rods of iron before rolling and drawing. In eliminating the need to weld and joint 192ft. lengths of wire at a time (the old method)⁵ Reid claimed he could make continuous lengths of some 2,000ft. This kind of improvement was directed particularly at the electric telegraph and was one reason for the growth in iron wire transmission lines. George Bedson (q.v.) was to apply himself to the same problem, but his solution was less satisfactory than Reid's and came some 13 years later.⁶ Copper wire did not answer well to jointing methods and this was one reason for developing a continuous wire-drawing method. The problems associated with jointing copper wire had been the cause of many problems surrounding the application of copper wire in those areas

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- 1 Bucknall-Smith J. A Treatise Upon Wire, Its Manufacture And Uses. Engineering and J. Wiley, New York 1891 p. 102.
- 2 British Patent No. 8133 p. 5.
- 3 A multi-block wire-drawing machine had been shown before that of Bolton's in 1875 (according to Singer - A History of Technology, Oxford 1958 Vol. 4 p. 622) and only one wire-drawing machine had been exhibited at the Great Exhibition of 1851 (Catalogue of the Great Exhibition Vol. 1 p. 292). The wire-train of S. A. Byrne was shown at the Glasgow Exhibition of 1885.
- 4 British Patent No. 3907 filed 15th June 1815. Bell was described by Prosser (op cit p. 52) as a "Walsall buckle-maker" but this could have alluded to another William Bell. As for the patent for wire, William Bell (of Birmingham), Prosser reminds us, obtained patents "precisely similar" to that of one W. E. Sheffield taken out in 1814 (Prosser op cit p. 170).
- 5 Preece W. H. Electrical Conductors p. 72.
- 6 British Patent No. 423 1859.

of electrical engineering where very long lengths and uniform dimensions were a pre-requisite. This was a point driven home by Davis:-

"There was a time when all joints of copper wire were hard soldered with brass and only roughly filed, not drawn. The wire that was joined in this way was made by shearing from rolled sheets of copper very narrow strips of nearly square wire, which was rounded by drawing through rough dies. The process was extremely unsatisfactory because of troublesome slivers that remained attached to the wire and because of the bulkiness of the joints. When in the '80's early dynamos were being constructed it was impossible to obtain suitable wire of considerable length because of the deficiencies of manufacture".¹

Though electro-welding,² which fused copper together by producing immense electrical currents across a joint (ohmic heating), helped solve jointing problems, it was a solution which ignored the ultimate remedy. Machines such as that made by Boltons', and contemporary American equipment of a similar type,³ could operate much more effectively if the initial rods presented to it were in themselves of extended length, and this was the whole problem surrounding the drawing of very long copper wire. In order to improve matters a way had to be found for the rolling mills to process larger "wire-bars" from the raw copper or iron billets or ingots. By extending the path length of rollers and ensuring a continuous uninterrupted process, very long rods could be rolled and drawn down into enormous lengths of wire. The first successful attempts were due to George Bedson (1820-1884). Some continuity in rolling mills was already in evidence in the 1860s when Bedson was most inventive.⁴ The method known as the "Belgium train" passed a rod through various shaped rollers which served to knead the hot metal into a homogeneous mass. This was laborious since men using tongs were required to carry and turn the rod

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- 1 Davis W. The Story of Copper . Century 1924 p. 224.
- 2 Ibid. p. 224. First proposed by Dr. Elihu Thomson later to form the Thomson and Houston Company which was to market electro-welding apparatus. This equipment was first seen in 1886. (See Encyclopaedia Britannica 13th Ed. op cit Vol. 28 p. 502).
- 3 Perrin F. A. op cit p. 65-67.
- 4 See for example British Patents:- 241 of 1862, 1085 of 1862, 1935 of 1862 and 2520 of 1862.

from roller to roller. Bedson's rolling-train, much more successful than his jointing, provided for a set of successive rollers, with each pair changing direction of rolling from the vertical to the horizontal.¹ This method had the ability to produce continuous rods and wire from billets weighing one ton.² Iron wire for telegraph lines became appreciably cheaper following the introduction of Bedson's techniques and was an additional factor in the demise of copper in this application. The Scots-American,³ William Garrett was next to contribute improvements to rolling mills when he introduced a high speed rolling technique on a multi-stage principle. The arrangement, well established by 1882,⁴ utilised as the first of its three distinct parts a "roughing train"⁵ which reduced a billet to a square rod approximately $1\frac{1}{2}$ inches square in cross-section. An intermediate rolling train (or "Dutch" train) reduced the rod to 1 inch but in doing so extended its length. Eight passes through the rolls (called the finishing-train) formed the rod into rounded wire-rod of No. 5 B.W. G. ready for the draw-bench. The Garrett Mill utilised variable speed rollers and could process not only at a very high speed, but operated with as many as five rods passing through the finishing roll at one time.⁶ So quickly did operations take place that the iron rod needed no re-heating during its rolling.⁷ This very efficient method became well adapted to the needs of the copper wire industry and with it, and similar methods, very long lengths of copper wire could be produced. Because cold drawing was not, as yet, carried out, hot rolled copper wire-rod was still in a stage of high conductivity; if this had been the case when the wire bar arrived at the roughing rolls. Cold drawing reduced the value of conductivity by about 2.5%, and it was in the drawing of

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1 Bucknall-Smith J. op cit p. 44.

2 Preece W. H. Electrical Conductors op cit p. 72.

3 Bucknall-Smith J. op cit p. 47.

4 Derry T. K. & Williams T. I. op cit p. 498.

5 Davis W. op cit p. 219. "The first (rolling) groove is called the 'roughing mill' and it is" !

6 Perrin F. A. op cit p. 39, 41.

7 Bucknall-Smith J. op cit p. 47-48.

the finer gauges of copper wire that strict attention needed to be paid to annealing processes. The greater the number of stages of reduction that the wire had to experience, the greater the probability of loss of conductivity. A problem which could only be overcome by very careful annealing. However, cold drawing and increased tensile strength were connected phenomena, sufficiently so for very high conductivity wire and poor tensile strength to be concomitant. Care in rolling became of prime importance; it was to be shown that higher tensile strength and improved conductivity depended much upon the mechanical affects experienced by copper during rolling. Poor rollers and guides, which indented, marked or overstrained the rod, eventually produced wire which at times had some 10,000 lbs. less tensile strength than copper rolled with close attention to the elimination of these problems.¹ The choice of rolling mill in the making of copper wire-bar became paramount, as did the selection of ores and the techniques of drawing. The optimum technique, of rolling and drawing very pure copper and finishing "hard" (i.e. without annealing), to produce copper wire of some 98% conductivity is attributed to T. B. Doolittle (1839-1921) who perfected the process in 1877.² In the same year, Doolittle had suggested that hard-drawn copper wire might be used for telephone and telegraph transmission lines, and following some experimental trials he succeeded in producing 500 lbs. of wire suitable for employment in an internal telephone system at the works of the Ansonia Brass and Copper Company (Ansonia, Connecticut). It was with this company that Doolittle was associated and most of the experimental work and the telephone system were sanctioned by the firm. Nevertheless, Doolittle faced severe difficulties, and spent many years perfecting a viable commercial process for hard-drawn copper wire. The technique that finally answered all the constraints set by the needs of large scale manufacturing consisted of reducing the wire in a much more gradual way than

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- 1 Perrin F. A. op cit p. 67. High conductivity wire tends toward a higher specific gravity than copper with a lower order of conductivity. Higher densities, and a much more homogeneous quality is found in copper which has been correctly treated in terms of heating, rolling and drawing.
- 2 Committee on Science and Arts The Journal of the Franklin Institute of Philadelphia 3rd series, 146, 1898 p. 158.

had hitherto been common in the wire mills. Draw-plates used by Doolittle had a larger range of die-gauges than ever before; each hole was only a little smaller than the one preceeding it and in this way it was possible to "- draw copper wire from the beginning to the end of the operation without any annealing."¹ The supreme advantage of this technique stemmed from the fact that a high conductivity copper rod could be drawn down to a fine wire without heat treatment, and without severe changes in its crystalline structure. This resulted in a high conductivity wire, with double the tensile strength and a minimised elongation under strain of 1%.² Consistent gauge throughout extended lengths meant that aerial transmission lines could be confidently expected to accept predictable strains. High uniform conductivity, in addition to uniform strength, could result in smaller gauges of copper wire spanning greater distances between poles; before this, unexpected variance (narrowing) in gauge coupled with low conductivity had demanded smaller spans with larger diameters of wire as compensation for defects. This had been a problem experienced by Cornell and many others who had turned first to copper wire for the early telegraphs. Doolittle's process overcame at once the main reason copper wire had been rejected and displaced by iron wire.

T. B. Doolittle made great efforts to bring his discovery to the attention of the operational telegraph companies.³ By 1883,⁴ the method had made it possible to introduce long copper transmission lines for the telegraph and telephone system of the U.S.A., where the new copper wire could now meet the requirements for the high tensile strength

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- 1 Ibid. "This method consists in using draw-plates containing a larger number of holes than the ordinary plates used in copper wire drawing, and increasing the number of passes for a given reduction in area".
- 2 Ibid.
- 3 Ibid.
- 4 Encyclopaedia Britannica 13th Ed. op cit Vol. 26 p. 554. See also Jrn. Franklin Institute op cit p. 158 "- it was due entirely to his persistant endeavours that hard-drawn copper wire was, at length, adopted for telegraph and long-distance telephone purposes".

aerial conductors necessary for economic spacing between telegraph posts.¹

It was to be the almost simultaneous upsurge in high-speed telegraphy, telephony and power transmission which changed the outlook for copper wire, and in this respect much of the work prior to the 1880s in continuous rolling and drawing techniques was nothing less than timely. By the 1880s the wire-drawing industry was beginning to restructure. Many old firms clung to traditional markets and out-dated methods of manufacture, while others saw areas for specialisation and moulded their manufacturing techniques in expectation of a huge demand for transmission lines. Yet other enterprises remained in the fore-front in both advanced manufacturing methods and the development of improved products. The trend in these directions had early been established with the introduction of submarine telegraphy and the companies which had grown from this work provided a second foundation for the copper wire industry, an industry which, up to the 1850s had in the main enjoyed only traditional outlets for copper wire.

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- 1 Thomas Benjamin Doolittle was both engineer and inventor. In his early life he manufactured brass articles at Bridgeport, Connecticut, and amongst his inventions for this time were a number connected with barbed wire. In the area of transport, he was the originator of the railway-car buffer-platform and coupler. He was associated with the Bell Telephone Company from its early days and originated the first telephone switchboard and the telephone call-bell. Doolittle retired from the American Telephone and Telegraph Company in June of 1909 and in the same year received an honorary ScD from Dartmouth College, New Hampshire. He received the Edward Longstreth medal from the Franklin Institute of Philadelphia in 1898 for his origination of the process for producing hard-drawn copper wire. (Who Was Who In America Vol. 1 (1897-1942) 3rd Edition. A. N. Marquis Co. 1943 p. 333). Doolittle's award was made on the basis that he was entitled to recognition:-
"(1) For having been the first to recognise the value of hard-drawn copper wire; and for having, by persistent endeavours, in the face of adverse conditions, succeeded in establishing its use for electric conducting wires: and (2) For his long continued experiments and labour in overcoming the many difficulties encountered in producing, on the commercial scale, a hard-drawn copper wire suitable for electric conducting wires." Journal of the Franklin Institute op cit p. 158, 159.

CHAPTER 10

THE CABLE MANUFACTURERS - ORIGINS IN OVERLAND TELEGRAPHY,
SUBMARINE TELEGRAPHY AND
TEXTILES

Though forced to compete with iron wire in overland telegraphy, copper wire formed an indispensable component in underground and submarine telegraph cables from as early as 1848. At this time, the firm of Siemens and Halske (Telegraphen-Bau-Anstalt von Siemens und Halske) laid Gutta Percha telegraph lines with copper conductors for the Prussian telegraph system.¹ Siemens and Halske, who had their beginnings with workshops at Schoeberger Strasse in Berlin (founded 1st October, 1847), were to grow into a huge concern with interests in almost every electrical device imaginable. At first, the company depended on other manufacturers* for its supplies of copper wire and this remained the case until it acquired the Kedeberg copper mine in the Caucasus in 1864² and proceeded to set up cable and wire works in a variety of locations. Siemens however, though established at Chalton,³ Woolwich, Berlin and later St. Petersburg (1882),⁴ were not to compare (in the scale of their operations for the production of copper wire) with a number of other firms spawned by the activities surrounding overland and submarine telegraphy.

Outstanding in these respects was W. T. Henley (1813?-1882) founder of the firm W. T. Henley's Telegraph Works Co. Limited. Abandoning the leather trade, in which he was brought up in his youth, W. T. Henley worked at a silk mercers and in the docks as a labourer, but during this time he taught himself science and conducted experiments.⁵

Though without schooling from the age of eleven,⁶ Henley learned well enough to take up the trade of philosophical (scientific) instrument maker and was to be employed by Charles Wheatstone in the construction of apparatus designed to assist in some of Wheatstone's

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1 Von Weiher S. "The Siemens Brothers -" Trans Newcomen Society XLV (1972-3) p. 1

2 Ibid.

3 Dixon H. N. Electric Cables Wires and Rubber. Cambridge 1952 p. 229.

4 Von Weiher S. op cit p. 2 and plates.

5 Dictionary of National Biography Vol. XXV p. 421.

6 Bowers B. Sir Charles Wheatstone H.M.S.O. op cit p. 140.

* Vide supra (footnote 1 and text) Ch. 11 p. 238.

experiments.¹ In 1837, Henley had a small workshop to manufacture silk and cotton covered copper wire, but after his dealings with Wheatstone (and Daniell) Henley moved on, and following the formation of the Bristol and Irish Magnetic Telegraph Company (of which he was the founder) Henley's prospects improved with the purchase of his patent for the magnetic needle telegraph.² In 1857, he began the manufacture of submarine telegraph cables at Enderbys Wharf, East Greenwich and in 1859 moved to larger premises on the Thames at North Woolwich.³ By 1863, Henley had committed his works to becoming entirely self-contained and to thus rid himself of a reliance on external supplies of wire. With this in mind, he very quickly set up wire-drawing facilities, rolling mills, stranding and insulating plants for copper wire.⁴ At one time, Henley's works covered between sixteen⁵ and eighteen⁶ acres and employed some two thousand men.⁷ It was to be said of Henley that as soon as he made money "he spent it on increase of plant".⁸ The company was still operational in 1953. One of the former chief electricians to W. T. Henley, S. E. Phillips,⁹ was to form (with C. Johnson in 1875) the firm of Johnson and Phillips - later to become renowned for cable making and in the field of power generation. Johnson had previously been associated with the Telegraph Construction and Maintenance Company (the result of the amalgamation between the Gutta Percha Company and Glass Elliot's of Greenwich in 1864). Johnson and Phillips' consumption of copper wire was great but the company did not manufacture any.

Before the amalgamation of Glass Elliot's with the Gutta Percha Company, the one remaining venture into submarine cable making of any significance was that of R. S. Newall

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1 Dictionary of National Biography op cit p. 421.

2 Ibid.

3 According to Bright (Submarine Telegraphs) op cit p. 158, these operations began in 1855, but there appears to be some doubt about this.

4 Sutton G. "Some Events in Cable History" Electrician Vol. 87, 1921 p. 607 see also Dictionary of National Biography op cit p. 422.

5 Black R. M. Electric Cables In Victorian Times H.M.S.O. 1972 p. 12.

6 Dictionary of National Biography op cit p. 422.

7 Ibid.

8 Ibid.

9 Bright C. Submarine Telegraphs op cit p. 160. See also Dixon H. N. op cit p. 230.

Newall's became the one other firm, besides Glass Elliot and the Gutta Percha Company, to be involved with the serving and armouring of the 1857 Atlantic telegraph cable.¹ Newalls' completed one half, while Glass Elliots' manufactured the other. R. S. Newall (1812-1889)² first came upon the field of submarine telegraphy when he displaced the firm of Wilkinson and Weatherly while they were in the process of covering the core of Crampton's 1851 cross-channel cable. After obtaining injunctions against E. Weatherly, on the strength of patents for wire-rope, Newall recorded that Crampton "found himself compelled to arrange with me for its (the cables) manufacture".³ From this point on, Newalls' contracted for more work in the manufacture of submarine cables and successfully laid three cables between England and Holland in 1853.⁴ Newall's continuance in the manufacture of submarine cables suffered a set-back however, when in 1857 it was realised that they and Glass Elliots' had manufactured their respective sections of the Atlantic cable with opposite twists in the armouring. Newalls' right-handed lay was not so conducive to coiling in the storage tanks, and the left-handed lay of Glass Elliots' was thereafter universally adopted.⁵ Newall's experience in wire-ropes is shown in a patent of 1857, which describes a method of rolling and redrawing a stranded copper wire conductor in an effort to eliminate "the charge".⁶ (Thought to be in proportion to surface area and considered a phenomena responsible for retarding transmission speeds). Newall processed the "rope" so as to reform the surface and remove the profile of each individual copper strand. Another patent of Newall's⁷ concerns itself with twisted fibres to insulate

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- 1 The drawing of the steel wire for the armouring of the 1865-66 Atlantic telegraph cable was the responsibility of one Birmingham firm, that of Messrs. Horsfall of Hay Mill, Coventry Road. By 1891 the firm had become Webster, Horsfall and Lean, but curiously retained the telegraphic address "Atlantic Birmingham". See Bucknall Smith op cit - advertisement No. v, and Dent K. Old and New Birmingham. Houghton Hammond, Birmingham 1881 section 3 p. 615. See also Seward G. The - Submarine Telegraph. London 1878 p. 52 (B.M.8756.df.13).
- 2 Dictionary of National Biography Vol. XL p. 309.
- 3 Newall R. S. Facts and Observations -. op cit p. 3. See also "The London Times" Letter page for November 12th 1852.
- 4 Newall R. S. Facts and Observations -. op cit p. 8.
- 5 Bright C. Submarine Telegraphs op cit p. 35. See also Newall's apology in the Mechanics Magazine No. 1774 (Vol. 67) for Saturday August 8th 1857 p. 129-130.
- 6 British Patent No. 1350 filed October 1857 p. 3.
- 7 British Patent No. 1379 filed June 1858 (Void).

copper conductors and it was in this important area that another company, W. T. Glover, originally entered the copper wire industry. Walter T. Glover (1846-1893)¹ began at the age of 22 with a small engineering works in Salford, and covered a wide range of engineering activities centred on the Lancashire cotton industry. During the course of his travels, he met George James, a Nottingham engineer. James held patents on machines designed to manufacture cotton braids and cords. The two men agreed to mutually promote their resources and by the 1870s the machines invented by James had been converted to apply cotton braids to iron wires "used for the support of ladies crinolines",² and for short lengths of lead wire used in hair curling.³ The machines were easily adaptable to the insulation of electric conductors, and after James had entered into partnership with Glover, the Salford works were turned over to two premises; the Salford Electrical Wire Works and the Bridgwater Street Iron Works. The electrical section began by making insulated cable for bells, signalling and telephone lines. The demand for electric cables and wire led, in the 1880s to the setting up of the Springfield Cable Works and a consequent expansion of the firms operations surrounding cable-making machinery.⁴ By 1882, the company was well established. An entry in the "Manchester of Today" Trade Directory for 1889 records Glover's achievements in drawing copper wire for the Manchester Jubilee Exhibition of 1887, where ten tons of copper was drawn into conductors to supply electric lights.⁵ The drawing of copper wire for electric light conductors was said to be "- their chief business"⁶ in this period, but a price list cites telegraph, telephon and electric bell wire as the company's principal products.⁷

Glovers' were fortunate to make an appearance at what can only be described as an

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- 1 W. T. Glover & Company Limited - Centenary 1868-1968 Manchester (private
publication) 1968 p. 1.
- 2 Ibid. 3 Ibid. 4 Ibid.
- 5 Ibid. p. 2. It should be noted that this firm was not connected with the St. Helens
firm of wire-drawers, William J. Glover, which was established in 1818.
(Bucknall-Smith op cit p. ix).
- 6 W. T. Glover & Co. Ltd. - op cit p. 2.
- 7 Ibid.

opportune moment in history. Their manufacturing capacity, coupled with the flexibility of youthful enterprise, enabled them to adapt quickly to the new electrical age. Their expertise was extensive and from the manufacture of cables to the drawing of copper wire, they gained an enviable reputation. By the early 1890s, they manufactured a full range of copper wire (0000 to 30 B.W.G.) and various tools and implements surrounding the applications of copper wire.¹ The Glover Standard Wire Gauge for measuring wire was based on a patent by Trotter and completed a range of equipments made by Glover to aid the installation, production and testing of copper wire.²

The meteoric rise of Glovers' is indicative of the rapid rise in the use of electrical cables and conductors from the 1880s. Three parallel developments, high speed telegraphy, telephony and the beginnings of power transmission were responsible for the expansion of electrical conductors and a brief resumé of this part of electrical engineering history will suffice to bring into context the changes seen in the wire industry by the end of the 19th century.

TELEPHONY, LIGHTING AND TRANSPORT - THE NEW ROLE OF COPPER WIRE

The introduction of high speed telegraphy, and telephony, in the 1880's showed for the first time the limitations and inadequacies of high resistance transmission lines. Speech transmission required special conditions to be present in the conductors if it was to remain intelligible and capable of reception at useful distances. Transmission was possible

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1 Bucknall-Smith J. op cit p. 150.

2 W. T. Glover & Co. Ltd. op cit p. 2. See also Chapter 8 on Wire Gauges.

however, over some of the newer copper and compound lines¹ which was evidence of the inroads copper was making in the area of overland telegraphy hitherto dominated by iron.

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- 1 Compound wire was the result of early attempts to combine the high conductivity of copper with the tensile strength of steel or iron. A. S. Bolton appears early in the history of this type of conductor with a patent for "Improvements in the Manufacture of Wire" taken out in January 1863 (B.P. No. 22). Using in this case copper alloy tubes for improved tensile strength, Bolton formed a composite conductor by inserting copper conductors (segmented or not) into the tube and subsequently rolled or drew the whole down to the required gauge. Bolton allowed for variations on this by including possible alternative arrangements for the sheath and its internal conductors. In all cases however, his intention was to make wire "- particularly applicable for electric telegraph purposes". (Ibid p. 3). By 1875, an American compound wire "consisting of a core drawn from cast steel" and covered with a ribbon of copper laid on helically and then tinned, was available. (Douglas J. C. Manual of Telegraph Construction London 1875 p. 250-1). This form of compound wire was not entirely successful (Preece W. H. Electrical Conductors op cit p. 75) due to deficiencies in early methods of manufacture. The invention of the helical tape compound wire is attributed to Moses J. Farmer (1820-1893) a long time experimenter with transmission lines (see Shaffner op cit p. 514) who began experiments about 1867 with one G. Milliken (also of Boston, Mass.) and produced a compound wire using a steel core and an envelope of pure copper; as with later types this was helically laid. The act of drawing the finished wire through a draw plate to "sweat" on the copper produced a marked improvement in the durability of this type of wire but in practice it was expensive. (Jrn. Soc. Tele. Eng. Vol. 1 1872-3 p. 284 Article - American Compound Wire). By 1883, the Farmer works has passed into the hands of the Postal Telegraph Company (U.S.A.). These works, at Ansonia, Connecticut (which were erected by Farmer and his associate Wallace) had gone over to the electro-deposition of copper by this time. Much improvement was gained in coating steel wire (.125 inch with copper by electrolytic means to a depth of .25 inches. Though very reliable, the expense of this kind of conductor precluded its use to all except long distance trunk lines. (Preece W. H. Electrical Conductors op cit p. 76, also Pidgeon D. Ibid p. 94). By 1873, 4,000 miles of compound wire was in use in the United States (American Compound Wire op cit p. 287). A final improvement in its production was made when it was found that electrolytically deposited compound wire (as opposed to helical tape wire) answered well to drawing through a draw plate thus reducing and compacting the composite materials (Preece W. H. Electrical Conductors op cit p. 95). Finally, it may be remarked that between 1844 and 1852 a series of patents on the preparing, coating and covering of metals (B.P. Nos. 9720, 10222, 10859, 11390, 11478, 13401, 13971, 14040) were granted to Edmund Morewood and George Rogers of the firm of Morewood and Rogers, Upper Thames Street, London. At the 1851 Great Exhibition, the firm exhibited "Compound Iron and Copper wire, the copper being external; possesses the strength of iron combined with the durability and conducting power of copper. Used for electric telegraph and - purposes to which copper wire is applied". A similar composite "coppered iron - wire" was shown by John Cornforth at the same time. Expense and competition from iron wire appears to have limited the success of both makers. (Cat. Grt. Exhib. Vol. II p. 161 & 630).

The hesitancy over the use of copper was as great in the mid 1880s as it had been 30 years before.¹ By this time however, copper cost mile for mile the same as iron but could be erected in finer gauges with an equivalent conductivity. Thus, high conductivity, hard drawn copper wire was now able to compete with iron since tensile strengths in copper could be sacrificed to some extent by improved conductivity; a factor which allowed for finer gauges of wire that needed to sustain comparably less (of its own) weight. In the winter of 1885-6 the Belgian Meteorologist F. van Rysselberghe carried out a series of experiments on different kinds of transmission line in an attempt to determine the various effects and the limiting distance for signal transmission over wires. Rysselberghe was later to comment "We tried iron wires and copper wires of several descriptions - with iron wires it (long-distance telephony) is quite impossible".² The experiments with copper wire had shown that it was the far better material for telephonic transmission except for a compound conductor, one of which linked New York and Chicago. Over 1,011 miles of compound circuit gave a "tremendous" result.³ In England, W. H. Preece (1834-1913) had resisted the idea of simultaneous telegraph/telephone transmission, which by 1887 was extensively used on the Continent and utilised routes totalling some 1,700 kilometers. These operated upon the Rysselberghe circuit for simultaneous transmission.⁴ Claiming that the English Wheatstone system of high speed telegraphy was inconsistent with the Rysselberghe methods, Preece, in his position as Electrician to the Post Office (confirmed in 1877),⁵ effectively blocked the advance of telephony in Britain, which thus became practically the last country in Europe to achieve long distance telephony.⁶ Preece's position in the Post Office made his voice one of some

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- 1 Johnson J. T. Discussion on Electrical Conductors op cit p. 100 - "It was asserted that No. 14 copper wire costing £87 per ton was as efficient a conductor as No. 8 iron wire costing £20, and that mile for mile it was not more expensive. That might be so, but he questioned whether it would be found as economical in practice. He thought that when it was scattered all over the country a good deal would be stolen
- 2 Van Rysselberghe F. "Long Distance Telephony" Jrn. Soc. Tele. Engs. XV 1886 p. 291.
- 3 Ibid p. 292. See also L'Electricien Vol. X No. 161 May 15th 1886 pp. 307-13.
- 4 Tucker D. G. "The Beginnings of Long Distance Telephony 1882-87" Electronics and Power October 1974 p. 826.
- 5 Tucker D. G. "W. H. Preece, 19th Century Telegraph, Telephone and Power Station Engineer" unpublished paper.
- 6 Ibid. See also Jrn. Soc. Tele. Engs. XVI 1887 p. 88-89.

influence and long-distance telegraphy was delayed primarily due to his insistence that a practical system of simultaneous high speed telegraphy and telephony was as yet to be proved.* In this respect Preece maintained a continued interest in the technicalities of long distance telephony and telegraphy, and initiated investigations of his own. He too, found copper the better conductor for speech transmission and was to form his KR law (the electric capacity by the line resistance - now CR) which gave him a figure of "goodness" for transmission lines. With this, Preece was to formulate the limiting distance for copper wires using experimental results which supported his theories; finding that overhead copper conductors were able to exceed in transmission distance overhead iron wires or underground copper cables.¹ In order to pursue these enquiries, Preece had begun by testing existing copper and iron wires as erected by the Post Office in 1885. At this time, Preece stated that:-

"Copper is gradually replacing iron for aerial telegraphs owing to its greater durability in smoky atmospheres; but its greater cost has led to the use of smaller sized wires. This can be done without detriment to the economy of the line for the resistance of Copper, as compared with iron, varies nearly inversely as its price per ton, and hence the cost per mile remains the same. Hitherto, only short lengths have been erected in smoky towns and through districts where chemical industries fill the air with gases destructive to iron wire."²

But there were to be other advantages to using copper besides durability as Preece concluded in his tests of a new Post Office transmission line between London and Newcastle. The transmission rate of high speed telegraphy was better in both the Simplex and Duplex modes (one way, and simultaneous send/receive) over copper, as compared to iron, by some 12%.³ Preece held that the superiority of copper was "- not simply due to

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1 Tucker D. G. W. H. Preece op cit.

2 Preece W. H. "On The Relative Merits of Iron and Copper Wires for Telegraph Lines" Report of the Fifth Meeting of the British Association for the Advancement of Science (Aberdeen) J. Murray 1885 Section A p. 907.

3 Ibid. p. 909.

* It appears that Preece disliked the idea that technical advances should find a lead outside of Britain. At a lecture to the Society of Arts in 1879, Preece defended the British telegraphic system and concluded by saying "England is not behind any other Country in the telegraphic development and it is not dependent on other countries for inventions and improvements". (Southern Echo, Southampton for May 16th 1879).

its smaller electro-static capacity and resistance; but that it is more susceptible to rapid changes of electric currents than iron."¹ Some support for this, which qualified Preece's arguments and put the phenomena on to a sounder scientific basis, was given by D. E. Hughes in his inaugural speech as President of the Society of Telegraph Engineers in 1886. Following experiments on the inductive capacity of metals, Hughes showed that self-inductance and wire diameters were co-related, and that iron was particularly self-inductive over the preferred range of wire gauges used in telegraphy.² Copper had relatively poor self-inductance and in single strand conductors:-

"- a difference will be felt on instruments depending upon rapid changes such as the telephone; and it is evident that the more rapid the contacts of a telegraph instrument the greater will be the difference between copper and iron."³

With apparently little regard for Hughes support, Preece continued his experiments with the full authority of the Post Office.⁴ Attempts to set up experimental lines free from telegraphic disturbance⁵ were first made difficult by the brittleness of the copper wire made available to him.⁶ Consultations with Thomas Bolton & Sons (Preece had met A. S. Bolton in 1883 at a meeting of the Institute of Civil Engineers) resulted in an arrangement between them and Preece. The firm supplied samples of copper wire drawn to varying levels of hardness and prepared from high conductivity electrolytic copper. Preece tested the wire for tensile strength and durability, the satisfactory results leading to a new specification for hard drawn copper wire to be supplied to the Post Office.⁷ The wire was to be graded in terms of weight - in pounds per mile of high conductivity copper⁸ -

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1 Ibid.

2 Hughes D. E. "The Self-Induction of an Electric Current in Relation to the Nature and Form of its Conductor" Jrn. Soc. Tele. Engs. XV 1886 p. 12.

3 Ibid. p. 22.

4 Tucker D. G. Long Distance Telephony op cit p. 827.

5 Tucker D. G. W. H. Preece op cit.

6 Baker E. C. Sir William Preece F.R.S. Hutchinson 1976 p. 201.

7 Ibid.

8 Bright C. Submarine Telegraphs - op cit p. 206.

and its production led to improvements in the methods of manufacture and the type of equipment used by Boltons'.¹ On Preece's insistence "- it was the biggest tussle I ever had",² the Post Office bowed to Preece's arguments over the economic advantages of a "copper standard". In the winter of 1886-7 a 150 lb per mile copper conductor was run from London to Nevin in North Wales. Telegraphy and telephone transmissions came over well, and on the basis of these experimental results, Preece consolidated his KR law,³ which was based on earlier work carried out essentially by Sir William Thomson in 1854.⁴ Preece ever maintained his conviction that only line resistance and capacity (ignoring inductance and other factors) could determine transmission limits, and though he was to face ridicule and to lose his credibility over the issue, he was undoubtedly one of the major influences in promoting the use of copper wire for communication purposes in Britain.

ELECTRIC LIGHTING AND TRACTION

Incandescent lighting was the second, and the most powerful stimulus for copper wire by the latter end of the 19th century. Electric lighting called for increases in conductors, dynamos and transformers, items which all required huge amounts of copper wire or copper ribbon. Examples abound of the lengths of wire used in early electric generators and other electrical devices, but in all cases they only serve to highlight the wide selection of copper wire in use, its availability and almost limitless application.⁵ The needs of

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1 Baker E. C. op cit p. 201.

2 Ibid.

3 Preece W. H. "Telephonic Investigations" Jrn. Soc. Tele. Engs. XVI 1887 p. 84.

4 Thomson W. "On the Theory of the Electric Telegraph" Phil. Mag. XI, 1885, p. 147-160.

5 Only one famous example may be quoted here, that of the Spottiswoode-Apps Induction coil described in the Philosophical Magazine for January 1877. This coil contained 2 primary coils:-

P1:- 660 yards of 0.96in copper wire with a total resistance of 2.3Ω and a conductivity of 93%!

P2:- 504 yards of 0.96in copper wire - conductivity 93%!

The secondary formed a cylinder 37.5 inches in length (20ins external and 9.5ins internal). 341,850 turns of wire (in 4 sections) required 280 miles of copper wire with a conductivity of 94%. (Spottiswoode W. "Description of a Large Induction Coil" Phil. Mag. 5th series, Vol. 3, No. 15, January 1877 p. 30).

submarine telegraphy, high speed telegraphy and telephony were in concert with power generation in influencing the quality and level of supplies from the wire-drawers. The cost of copper however, and its extravagant use in early low voltage D.C. lighting systems resulted in efforts to simplify circuits in answer to the demands of economy,¹ reliability and easy maintenance. The electrical engineer, Charles F. Brush, appears early to have considered the wide market for street lighting by arc-lamps, and by 1879 had concluded that to produce a commercially viable system, the costs of manufacturing dynamos, the operating cost of each lamp and the cost of the copper conductors (the "Copper cost"), all required serious examination.² High current, low voltage systems required substantial conductors to minimise power losses in the small but significant resistances of long power conductors. Brush devised a high voltage dynamo to counter the problem; the small voltage drop across long conductors represented only a small power loss.³ The inventor and engineer, T. A. Edison (1847-1922) faced much the same difficulty. It had been common to provide for uniform voltages in lamp circuits by having a parallel "feed" network so that the conductors nearer the dynamo were thicker than those after the first lamp and so on up to the end of the parallel system. A very large investment in copper wire of various gauges was required, and Edison at one time arrived at a total cost of \$25 per lamp in a self-contained electric light system.⁴ Lamps with carbon filaments drew more current as they became hotter (negative temperature coefficient) - Edison saw that if he used a set of two wires as "main" conductors and used these to feed a second parallel circuit, then the copper cost could be significantly reduced and the lamps would operate at a constant voltage (the "feeder" taking most of the voltage drop).⁵

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- 1 It was later to be admitted that much extra cost was due to engineers failing to specify exactly when ordering conductors:- "- instead of asking for a cable of fixed resistance per mile, (they) are apt to specify a certain percentage conductivity according to Matthiessen's standard and a certain cross-sectional area. If therefore a manufacturer is able to take advantage of inexactitude in both definitions the user of the cable will be increasing his copper losses by 4%." (Editorial, The Electrician March 16th 1900 p. 743).
- 2 Passer H. C. The Electrical Manufacturers 1875-1900. Harvard 1953 p. 17.
- 3 Ibid.
- 4 Ibid p. 178.
- 5 Ibid.

This type of circuit rationalisation for copper costs made the private and public supply of electricity much more practicable. So valuable were the methods of reducing copper costs, that Edison¹ and St. G. Lane Fox² took out patents for novel wiring networks in preparation for public electricity supplies. Theoretical considerations had been proposed by William Thomson in an attempt to formulate an optimum size of conductor with regard to the price of copper and the amount of current to be carried.³ According to Thomson, the annual value of wasted energy (described as heat loss in the conductor, or copper loss) should equal the interest on the capital expended in laying down or putting up the conductor. Some interpretations preferred to see Thomson's law of economy as one which asserted that the current should always be proportional to the sectional area of the conductor.⁴ Thomson had arrived at a figure of 322 Amperes to the square inch of copper conductor (with copper at £70 per ton and with interest at 5% operating over 12 hours) and William Siemens had reached a value of 390 Amperes at £90 per ton and interest at $7\frac{1}{2}\%$ on the assumption that operations proceeded for 8 hours. Such examples show that the computations and the substituted values were of times a matter of convenient argument.⁵ In practice, however, such supposed theoretical limitations depended much upon the conductivity of the copper and as conductors improved, examples were attested to of conductors much improving upon the predicted minimum level of economy.⁶ Considerations of this kind diminished in importance however, with the introduction of high voltage A.C./D.C. supplies.

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- 1 British Patent No. 5306, 1878 and British Patent No. 602, 1880.
- 2 British Patent No. 3988, 1878.
- 3 Thomson W. "On the Economy of Metal in Conductors of Electricity" 51st Brit. Assoc. Adv. Sc. 1881 (York) Murray 1882 p. 517, 526-53. See also J.H.C. - Reports From Committees XI, 1878/79 p. 193.
- 4 Blakesley T. H. Discussion on Electrical Conductors op cit p. 108.
- 5 Nevertheless, Preece was to say that "Any departure from this (Thomson's) law, to secure lower capital expenditure, means shortsighted policy and non-scientific practice." Preece W. H. Electrical Conductors op cit p. 67.
- 6 Blakesley T. H. Discussion on Electrical Conductors op cit p. 109. The answer was to be arrived at by means of higher supply voltages and lower currents - a lesson that should have been learned from C. F. Brush. See also Preece W. H. Mains for Electric Lighting J.I.E.E. XX 1891 p. 411.

This kind of investigation was nonetheless valuable and constituted a basis for progress. For the wire industry, each new development influenced its course, and seldom failed to reinforce the ever incessant call for increased quantities of better conductors. Cheapness and high conductivity were factors as important in the rise of electrical distribution as the invention of the electric motor, the dynamo, the electric lamp or the transformer. Without the resources of a progressive wire industry, the expansion of the electric supply industry would have been stunted. However, it is worth noting that even in that era, deficiencies in the quality of copper wire were able to retard progress in electrical engineering (in the late 1880s, Elihu Thomson complained that he had difficulty in securing high conductivity copper wire).¹ But on balance, the wire industry responded quickly to demands for a consistent standard of quality in electrical conductors and as such, contributed much to the well being of society. Electric transport in urban areas expanded commerce and population mobility with the arrival of electric-tramways (as a speedy replacement for horse-drawn omnibuses). Early electric-trams were seen in Germany in 1884 and had reached England by 1891.² Once again, the copper wire industry played an important role in this innovation. The technical aspect of drawing "trolley-wire" and commutator copper (for motors and dynamos) had been of concern to A. S. & T. Bolton of Thomas Bolton & Sons from the mid '80s.³ The technicalities of providing facilities for the rolling of rectangular copper sections, and forming copper stranded rope,⁴ were peculiar to the electrical industry, requiring high capital investment on the part of the wire industry, an act which demanded of it no little commitment to the new electrical age. This attitude was general amongst the new order of wire-drawers. Investment in the developing electrical supply industry was an act of faith. The returns that such faith could provide are reflected in the condition of the European and American wire industries at the end of the 19th century.

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- 1 Passer H. C. op cit p. 356. E. Meylen showed that copper was still subject to variable levels of purity - four samples bought at random had a 4-1 ratio in conductivity. (*L'Electricien* Vol. 1 1893 p. 344). Lagande however noted copper purities of 96.26% in 1898 (*Notes - Pure Copper Wire* *Jrn. Inst. Elec. Eng.* Vol. 22, 1898, p. 633).
- 2 Derry T. K. & Williams T. I. *Short History of Technology* op cit p. 387.
- 3 *Bulletin Non-Ferrous Metals Research Association* op cit p. 4.
- 4 *Ibid.*

CHAPTER 11

THE WIRE DRAWERS - A SECOND GENERATION

A number of firms which formed an important part of the copper wire industry at the end of the 19th century have received due comment at various times in this work. The firms of Thomas Bolton & Sons, W. T. Glover and W. T. Henley's Telegraph Works Company are examples of enterprises which remained ever progressive well into recent times, and their position during the final decades of the 19th century have been cited through many instances of enterprise or contribution to the wire and associated electrical industries. Apart from these companies, all of which were born of the English manufacturing industries, many continental and American wire mills had developed during the course of the Victorian era. Their organisation and disposition contrasted markedly with their English counterparts; few English mills could match them in size and concentration of plant, an element of their enterprise that was to be characteristic of these foreign competitors, only in a few cases could the English mills compete in terms of capacity and output. Of the British mills active at this time, many concerned themselves only with ferrous products - thus Warrington, for example, (an area involved in wire-drawing from the end of the 18th century)¹ tended to favour wire mills based exclusively on iron and steel wire. This was common also to many foreign mills. There were exceptions at Warrington (and elsewhere) notably the Warrington firm of Messrs. Ryland Brothers. Nonetheless, like many wire mills which went to make up the English copper wire industry, Rylands' pledged themselves to no one type of wire. This attitude was general amongst wire-drawers and was typical of early, middle and late 19th century mills. What acknowledgement to the importance of copper wire did exist is apparent in a perceptible emphasis placed on copper wire (at times in the form of telephone, telegraph and electrical conductors) in the advertising literature of various mills. Like many of the Birmingham wire-drawers in the middle 1900s, it was considered unwise to put all one's eggs in one

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1 Bucknall-Smith J. Treatise Upon Wire op cit p. 3.

type of wire notwithstanding a large investment in copper wire processing. The exceptions to this are confined to the wire mills traditionally concerned with non-ferrous metal working, of which a prime example was Thomas Bolton & Sons. Here, as with a number of similar Birmingham firms, much reliance was placed on the continuance of a market for copper wire, and though it might be true that copper was as equally important as any other wire for many concerns, it must be remembered that in general the manufacturing capacity of a wire mill could be given over (at any one time) to the manufacture of a variety of wire, depending upon current orders. Expertise however, could be different for particular types of wire in different mills. This being precisely the case for companies like Boltons', W. T. Glovers', Everitts', and Moores' etc., with whom copper wire was a speciality.

The firm of Johnson and Nephew, (correctly Richard Johnson and Nephew) traced its origin to the Manchester district and was established in 1789.¹ The mills were described at the end of the 19th century as being the most modern; there being "- probably no better example".² At this time, the firm had premises at Alderwasley, near Derby, and original works at Dale Street, Manchester.³ At one time, the two wire mills in Manchester and Ambergate were to employ some 1,000 hands.⁴ The Manager of the Manchester works was eventually to be George Bedson⁵ who initiated rod rolling trains (following a series of patents) in 1862⁶ and provided the company with the first continuous rod-rolling mill outside the United States. Bedson joined what was at the time, Richard Johnson and Brother (Johnson and Nephew from 1877) in 1851⁷ after leaving the two Warrington firms of Rylands

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- 1 Richard Johnson and Nephew - Advertisement - Bucknall-Smith J. op cit Ad. No. ii.
- 2 Bucknall-Smith J. op cit p. 46.
- 3 Richard Johnson and Nephew - Advertisement - Bucknall-Smith J. op cit Ad. No. ii. Johnsons' were the only firm to exhibit wire-drawing equipment at the Great Exhibition of 1851. Cat. Grt. Exhib. Vol. 1 p. 292 Exhibit 212.
- 4 Bucknall-Smith J. op cit p. 93.
- 5 British Patent No. 423, February 1859, p. 1.
- 6 Singer C. op cit p. 621.
- 7 Bucknall-Smith J. op cit p. 45.
- * Everitts' and Paul Moore and Co. emphasised the manufacture of copper wire but of the two concerns, Moores' were by far the most enterprising. See footnotes Ch. 8 p. 196 and Ch. 1 p. 75.

Brothers,¹ and James Edleston and Company - a firm he joined in 1839 at the age of 19.² Bedson worked at Johnsons' for 33 years until his death in 1884.³ The company was a private concern with ownership by hereditary claim. By 1900, however, the third generation held only a junior partnership.⁴ The mills manufactured a whole range of wire which included "conductivity and high strain materials - galvanised telegraph and telephone wire and "cable" wire".⁵ The drawing of copper wire was emphasised somewhat more in the range of products manufactured by the Warrington firm of Rylands Brothers, a concern which was founded in 1805.⁶ The history of this company is complicated and begins with a Captain Ainsworth, whom in 1800 "projected works" in the Warrington area with a "practical wire-drawer named Nathaniel Greening".⁷ The project did not advance and Greening is next heard of joining John Rylands, with the original intention of setting up a wire mill still in mind. A works was equiped and began manufacture in 1805 and continued until 1840 when the partnership was dissolved. Both Rylands and Greening brought their sons into business - Rylands' became Messrs. Rylands Brothers (when the father was succeeded) and Greening set up business styling himself Messrs. Greening and Sons.⁸ By 1868, Rylands' turned their business into a limited company and continued to prosper. In 1891, the Church Street works at Warrington were entirely self-contained and could boast 29 separate departments for the various activities surrounding metal processing and wire-drawing.⁹ The works covered an area of approximately $5\frac{3}{4}$ acres which included a fine wire mill of two storeys and two other mills of 3 and 2 storeys respectively. The firm

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1 Bucknall-Smith J. op cit p. 4.

2 Ibid p. 45.

3 Ibid.

4 Ibid p. 93.

5 Richard Johnson and Nephew - Advertisement - Bucknall-Smith J. op cit Ad No. ii.

6 Rylands Brothers Limited, Warrington - Advertisement - Bucknall-Smith J. op cit.

7 Bucknall-Smith J. op cit p. 3.

8 Ibid. He continued in business until 1851, Greening then moved to Canada, and the original firm continued in Warrington as N. Greening and Sons.

9 Bucknall-Smith J. op cit Figure 25 p. 94.

manufactured wire, wire ropes, netting springs and barbed wire.¹ The wire production was of "all kinds - iron, steel, plain, galvanised, tinned, coppered, telegraph and telephone."² The last three items were catered for by the smelting shop, while it is interesting to note that the manufacture of barbed wire became a lucrative practice for Rylands' and many wire concerns at this time. Rylands' were to foster three renowned names in wire-making: Bedson, who worked for Rylands' until 1851,³ G. E. Woods (the son of a master wire-drawer from Rylands') who opened the Longford mill in Warrington,⁴ and Thomas Monks who began the Whitecross Company in 1864.⁵ Within thirty years, these Whitecross rolling and wire mills became one of the most extensive and important in the world, and compared favourably with some of the larger foreign concerns. At this time, the company employed no less than 800 workers and had within the works 40 boilers generating 4,000 Imperial horse power. The premises had direct railway links and access to canals.⁶ The rolling mills could produce 35,000 tons per annum and the wire mills were so laid out as to be able to draw $\frac{1}{2}$ inch rods down to No. 40 Standard Wire Gauge. The firm specialised in copper wire, both tinned⁷ and high conductivity, designated as "low resistance telegraph and telephone wire".⁸

The American counterparts of the larger English mills became as expansive as the English mills were compact. Washburn and Moen, a firm which by the middle 1890 s had works covering some 50 acres⁹ (compared with 11 acres in 1875) was established at Worcester, Mass., about 1831.¹⁰ Initially, the firm had been the concern of Ichabod

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- 1 Rylands Brothers Limited, Warrington - Advertisement - Bucknall-Smith J. op cit.
- 2 Ibid.
- 3 Bucknall-Smith J. op cit p. 45.
- 4 Ibid p. 4.
- 5 Ibid p. 4, 97. Monks was in fact the original manager of the works and was foremost in its erection - the financial principal and administrator was one, R. Murray.
- 6 Ibid p. 95.
- 7 Ibid p. 96.
- 8 The Whitecross Company - Advertisement - Bucknall-Smith J. op cit.
- 9 Ibid p. 123.
- 10 Washburn I. Autobiography and Memorials of Ichabod Washburn. Editor H. T. Cheever, D. Lothrop & Co., Boston 1878 p. 46, 190. See also The Dictionary of American Biography, Scribner 1936 p. 501, and Bucknall-Smith op cit p. 123.

Washburn (1798-1868) and a Benjamin Goddard (who had been associated from 1823).¹ In 1832, the draw-benches produced only fifty pounds of wire a day but within two years this output had increased to seven hundred pounds per day.² In 1833, the company began trading under the name of Washburn and Company,³ Goddard having relinquished his interests in the same year.⁴ By 1850, most of the iron telegraph wire used in the United States (some six thousand tons per annum) was made by Washburns'.⁵ Following a policy of continuous improvement in its product range, the company offered facilities for experimental work and during the period 1853-1859 the American Telegrapher, T. P. Shaffner attended, and conducted, a series of experiments at Washburns' works on the improvement of iron telegraph wire.⁶ Much work was also done under the direction of Phillip Moen (Washburn's son-in-law) who became Washburn's partner in 1850.⁷ In the same year, the company introduced galvanised iron telegraph wire⁸ and in 1869-70, a year after Washburn's death, began operating a system of "continuous rod-rolling".⁹ Despite being twice devastated by fire, the company continued to expand on all fronts and by the end of the 19th century could offer iron, steel and barbed wire, piano wire and copper wire amongst its range of products.¹⁰ Washburn and Moens' works became practically self-contained and in the last decade of the 19th century provided employment for 3,000;¹¹

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1 The Dictionary of American Biography op cit p. 501.

2 Washburn I. op cit p. 50, 190.

3 Shaffner T. P. op cit p. 519.

4 Washburn I. op cit p. 46.

5 Shaffner T.P. op cit p. 520. It was said that "When the invention of the telegraph had induced an extensive demand for wire for telegraphic purposes, Mr. Washburn devoted his attention to the manufacture especially of Galvanised Wire which is a better conductor of the electric fluid than ordinary wire" ! Washburn op cit p. 50 and 190.

6 Shaffner T. P. op cit p. 519, 521.

7 Washburn I. op cit p. 47 and Dictionary of American Biography op cit p. 501.

8 Washburn I. op cit p. 50 and Dictionary of American Biography op cit p. 501.

9 Perrin F. A. op cit p. 36 and Bucknall-Smith J. op cit p. 124. The system was devised by W. H. Daniels, Engineer with Washburns' (Perrin F. A. op cit p. 48).

10 Bucknall-Smith J. op cit p. 123.

11 Ibid.

evidence of continued expansion when compared to the 1,300 employees of a decade earlier.¹ Nevertheless, even at that time the mills produced "- sixty thousand pounds (of one hundred varieties) of finished wire - equal to a yearly sale of 11,000 tons" valued at \$2m.²

Similar in standing to Washburns' at this time was the American firm of John A. Roebling's Sons Company. Though the works of this firm eventually covered only 25 acres³ (as compared to Washburns' fifty) the firm was to claim itself as "- the largest in the United States".⁴ While perhaps not strictly true in terms of the scale of their works, as regards output, capacity and reputation there were few equal.⁵ The firm originated from a small hemp rope works set up by J. A. Roebling (1806-1869) in the 1840s and in 1841 the tiny factory produced the first wire-rope to be made in the United States.⁶ In 1849,⁷ Roebling moved to a new factory at Trenton, New Jersey and operations remained there for the rest of the 19th century.

In June of 1857, Roebling wrote to A. S. Hewitt and proposed the building of a bridge over the East River to connect Brooklyn and Manhattan, however it took ten years before a charter was granted for such an enterprise and final approval only came in 1869.⁸ The plan to build the Brooklyn Bridge was for Roebling a triumph; he was made engineer-in-charge and his company was commissioned to manufacture the wire ropes demanded by the design which itself was based on Roebling's expertise in building suspension bridges. Ultimately, however, the operation not only established Roebling's reputation, but cost him his life. While inspecting pilings in the early stages of construction, he injured his foot (crushed when a ferry-boat moved the pilings).⁹ A tetanus infection, resulting directly from the foot injury, proved fatal. Roebling died on Thursday 22nd July 1869, 24 days

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1 Washburn I. op cit p. x.

2 Ibid.

3 Bucknall-Smith J. op cit p. 122.

4 John A. Roebling's Sons Company - Advertisement No. vii, Bucknall-Smith J. op cit

5 Ibid. p. 122.

6 Dictionary of American Biography, Oxford University Press Vol. XVI 1935 p. 88.

7 Ibid. See also Bucknall-Smith J. op cit p. 122.

8 Dictionary of American Biography, Oxford University Press op cit p. 88.

9 Ibid.

after being injured.¹ The bridge was completed by Roebling's eldest son, Washington Augustus Roebling, in 1883. When John Roebling died in 1869, the works continued generally under the Directorship of his nine sons, but principally W. A. Roebling, the eldest.² According to Bucknall-Smith,³ Roeblings' were the first to utilise the "Belgian train" rolling system in the United States. By the 1870s however, they had introduced the "looping in" system of rolling, a method very similar to that devised by Garrett.⁴ (It appears nevertheless, that even as late as 1903 the Belgian train system was still in evidence).⁵ Roeblings' range of products came to depend upon copper wire to such a degree that by the 1890s it stood as important in their sales as their principal interest, steel and iron wire and rope. Advertising at the time, Roeblings' emphasised their range of "Electric cables and conductors, iron and copper telegraph wire" and "Insulated electric wires".⁶ To cater for these products, Roeblings' could depend upon four extensive wire mills. Telegraph wire was made in a mill which contained no fewer than thirty draw benches;⁷ coated (insulated) wire was drawn in an equally spacious mill which operated some twenty five machines, while the fine wire-room boasted approximately sixty drums, blocks and dipping baths.⁸ The heavy wire-drawing room at Roeblings' contained ten benches with their associated equipment.⁹ The coating-room and the fine wire-room were both lit by electric light. The company took pains to produce high conductivity copper wire of good mechanical quality,¹⁰ and jointing (for long lengths of copper wire) was achieved by means of the Thomson-Houston company's electro-welding apparatus.¹¹

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- 1 Who Was Who In America op cit p. 451.
- 2 Dictionary of American Biography, Oxford University Press op cit p. 89.
C. G. Roebling later, in 1890, took over as President. See Bucknall-Smith J. op cit p. 123.
- 3 Bucknall-Smith J. op cit p. 123.
- 4 Perrin F. A. op. cit p. 39.
- 5 Ibid p. 55.
- 6 John A. Roebling's Sons Company op cit.
- 7 Perrin F. A. op cit p. 57.
- 8 Perrin F. A. op cit p. 62, 63.
- 9 Ibid. p. 68.
- 10 Bucknall-Smith J. op cit p. 123.
- 11 Ibid. Vide infra Ch. 9 p. 212.

Of the European wire mills in the 19th century (besides those in Britain) three may be noted, Eisen Industrie zu Menden und Schwerte, the Westfalische Union and Felton and Guilleaume. The first named company was formed in 1836 and by 1900 produced some 70,000 tons of combined wire products including copper conductors.¹ Like its two principal rivals, the company was one amongst three wire concerns in the German states which over-shadowed nearly every other Continental wire mill. The Westfalische Union was formed through an amalgamation of several old Westphalian wire-works and established its H.Q. at Hamm in 1873.² The combined output of the corporation approached 100,000 tons per annum and employed 3,300 hands.³ Of the three major German wire manufacturers at this time however, the firm of Felton and Guilleaume remain outstanding in the copper wire industry. Established in 1750 by J. T. Felton,⁴ the company remained a minor concern until about 1830 when the business at Cologne became controlled by the Guilleaume family. The interest rapidly developed from this period and the works were transferred to new premises at Mülheim-on-Rhine in 1873.⁵ By 1890, the mills and shops covered some 80 acres monopolised by a vast complex of wire-drawing and wire processing departments. The staff of 2,500 could call on laboratory facilities and a good technical library.⁶ Contemporary advertisements for this period described the firm as having some thirty different items available directly from stock, and included amongst these were copper wire, copper wire ropes, copper telegraph, copper telephone wire and electric light conductors.⁷ Photographs of the establishment at the end of the 19th century, show a factory complex with nine major buildings, railway yards and twelve unobtrusive chimney stacks. The majority of the 80 acres of works area appear well saturated by mills and workshops, with little free area.⁸ The firm appears to have supplied Siemens and

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1 Ibid p. 97.

2 Ibid.

3 Ibid.

4 Ibid p. 5.

5 Ibid p. 117.

6 Ibid p. 118.

7 Felton and Guilleaume - Advertisement - Bucknall-Smith J. op cit.

8 Bucknall-Smith J. op cit p.119. Illustration of Felton and Guilleaume works at Mülheim.

Halske with conductors for the 1848 Prussian telegraph system¹ and in later years made, and laid down, an extensive network of telegraph cables.² With the new call for electric light installations, the firm had, by the late 1890 s installed numerous central lighting stations which incorporated their own insulated conductors. Stations at Barmen, Hamburg, Bremen and Lubeck may be cited.³

Some mention should be made of Frederick Smith and Company of Halifax, and the very specialised Phosphor Bronze Company, both British concerns, in concluding this chapter. Frederick Smith operated from the Caladonia works in Halifax⁴ and achieved a high reputation as wire-drawers, and manufacturers of wire-drawing machinery. Fitzpatrick called upon Smiths' to draw some of the wire used in his repeat of Matthiessen's work, and the company became renowned by the 1890s as a manufacturer of very high grade copper wire, a commodity amongst a whole range of iron, steel and coppered wires produced by Smiths'. Within the range of copper wire manufactured by Frederick Smith, very high conductivity copper wire was emphasised as too was hard-drawn copper wire (from No. 8 to No. 18 B.W.G.),⁵ "annealed, tinned or plain" copper wire and copper strand and tape for lightning conductors.⁶

The Phosphor Bronze Company was set up in 1874 to exploit the patents on alloys of copper, tin and phosphorous. The high tensile strength of such alloys, invented by the American, C. A. Dick, in 1871-72⁷ lent themselves to overhead telegraph lines, but comparatively poor conductivity disqualified the material from being a full competitor of copper. However, some Phosphor-Bronze line was brought into service with the British Post Office in 1877-78 but it found a place only in localities requiring lines of extreme span e.g. from the Swansea headland to the Mumbles lighthouse. In such a situation, very

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1 Ibid p. 121. This is not absolutely established but seems very likely on the evidence available. The experimental cables of 1848 were laid by Siemens between Berlin and Frankfurt, whereas Feltons' laid down cable between Berlin and Halle. According to Bucknall-Smith "The first telegraph wire for the Prussian Telegraph Department was drawn by this firm" and at this time (1848) Siemens' were not in a position to draw their own wire having only just established themselves.

2 Ibid.

3 Ibid.

4 Frederick Smith and Company - Advertisement - Bucknall-Smith J. op cit.

5 Bucknall-Smith J. op cit p. 141.

6 Frederick Smith and Company op cit.

7 Bucknall-Smith J. op cit p. 105.

high tensile strength would be favoured in preference to considerations of conductivity (i.e. 20% of that of copper) for what was electrically a short distance.¹ The Phosphor Bronze Company continued to prosper however, when it found alternative outlets for the metal. As spring wire in seamless tubes, sheet metal, surgical ("Doctors") blades and cycle spokes,² the alloy found a ready market. By 1890, the company acknowledged the deficiencies of Phosphor Bronze as a conductor for overhead telegraph and telephone lines and had turned its attention to "Silicium-Bronze", an alloy patented by Lazare Weiller in Germany in 1882.³ Though the alloy contained little residual silicon as such,⁴ the process provided a wire with a conductivity 40% that of pure copper, $\frac{1}{4}$ the weight of iron with a tensile strength approaching that of steel.⁵ Though the new alloy was to be extensively used in telegraph lines (and later telephone lines) its durability and conductivity, coupled with high tensile strength made it ideal for other tasks. Weiller's three separate patents for the material became the sole property of the Phosphor Bronze Company, but these applied only to British and Colonial rights⁶ and when in the 1890's the American Bridgeport Brass Company came out with a new Silicium-Bronze wire, a new application for the alloy was opened up.⁷ The new wire, 98.75% copper, 1.25% tin and fluxed with a 15% silicon-copper "hardner" was called "Phono-wire" since it was intended for telephone circuits.⁸ The material was most successful as trolley-wire for heavy street railways, an application in which it displaced copper wire, since in this respect it was three times as durable.⁹ Nevertheless, the market for the various "bronze" alloys was more than sufficient, and the few companies involved in this field (Weiller in France and Bridgeport Brass in the United States for example) did little to prevent the Phosphor Bronze Company

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- 1 Preece W. H. Electrical Conductors op cit p. 76. The German Telegraph Department discontinued tests on Phosphor Bronze wire in 1881-82 due to unfavourable results (Article - Jrn. Soc. Tele. Engs. Vol. XI 1882 p. 407).
- 2 The Phosphor Bronze Company - Advertisement - Bucknall-Smith op cit.
- 3 Thum E. E. "New Copper - Silicon Alloys -" Metal Progress Vol. 33, 1938 p. 258.
- 4 Ibid. See also Bucknall-Smith J. op cit p. 106.
- 5 Bucknall-Smith J. op cit p. 106.
- 6 Ibid p. 108. Also Phosphor Bronze Company Advertisement.
- 7 Thum E. E. op cit p. 258.
- 8 Ibid.
- 9 Ibid.

from flourishing. However, as a token of acknowledgement to the possibility that Silicium-Bronze might loose favour, or indeed was not universally applicable, the Phosphor Bronze Company reminded patrons that it manufactured "Copper wire (Best High Conductivity and Ordinary), Brass wire, rods and sheets".¹ In the event however, no dependence on "standard" commodities was needed and the rolling and wire mills of the company (at Bagot Street, Birmingham) continued to fill the needs of various telephone authorities throughout the world. The company's most prosperous time was to come after the close of the 19th century, a period when Silicium-Bronze displaced hard-drawn copper wire as the major overhead conductor for telephone, telegraph and transport circuits.

As with the developing expectations of the Phosphor Bronze Company at the close of the 19th century, three other concerns may briefly be cited whose fortunes improved with the new favour given to copper alloys in their role as durable overhead conductors. The Yorkshire firm of Ramsden Camm, for example, had from the 1890s an interest in copper and phosphor bronze wire production, and it developed this facility with considerable foresight, bringing the production of non-ferrous wire products in line with its range of iron and steel wire, ropes, rods, screws, nuts and staples.² Similarly, the Aluminium Brass and Bronze Company of Bridgeport, Connecticut³ and the Ansonia Brass and Copper Company⁴ (Associated with T. B. Doolittle) both prospered as the market for copper alloys expanded.

In reviewing the manufacture of copper wire during the final years of the 19th century, it is notable that the production of this one commodity did not dominate any country's wire industry and only rarely could it be found as the exclusive product of a wire mill. I have given some of the reasons for this; but a fuller explanation requires that some attention be given to other circumstances prevailing in the period and industry under discussion.

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1 The Phosphor Bronze Company op cit.

2 Ramsden Camm - Advertisement iii - Bucknall-Smith J. op cit.

3 Bucknall-Smith J. op cit p. 124.

4 Vide infra p. 214.

Diversification in the wire industry was in general a matter of convenience, due to the nature and flexibility of the wire-drawing process (common to most metals), it was also a deliberate act in many cases designed to afford a measure of protection against market fluctuations in any one commodity price. It would seem reasonable that a firm capable of mastering the process of drawing a marketable wire would endeavour to improve its profits by producing a complete range of wires, not only in a variety of gauges but of different metals. That the wire-drawing process allowed for the making of ferrous and non-ferrous wire enabled a greater market to be sought and provided a certain amount of economic protection to the wire-drawers. Moreover, the expertise in handling and processing any given metal (copper for example) leads, inevitably it can be argued, to the manufacturing resources capable of working that metal into sheet, bar, rod, tube and wire.¹ The same is true where ferrous products are undergoing manufacture. Product diversification due to an inherent manufacturing flexibility, rather than a deliberate re-equipping to extend the product range, is a natural progression which tends toward stability and self-protection.

Such measures, however, whether contrived or not, were principally responsible for the fact that up to 1890 the wire mills that constituted the copper wire industry tended to blend into the general wire industry. This was particularly true of the English wire-making industries. The realisation of an entirely separate copper wire industry (with the coming of power transmission and the anticipated orders for large amounts of conductors) was less than instantaneous if not sluggish. This was due largely to the merging of copper wire manufacture with other products, traditional restraints and the reluctance of new companies to form and exploit the expected demand. Fragmentation of concerns within the wire industry was less likely too, and in any case the English wire industry had suffered a blow in its hopes to expand copper wire production following the depressed state of all industries concerned with electrical supply following the 1882 Electric Lighting Act. Although some £8 million² had been lost in unsound enterprises into electric lighting, the six years in

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1 Copper wire making involved the rolling of sheet and rod. Tube making was in the main based on copper sheet.

2 Barnes C. C. "Power Cables Old and New" Electronics and Power June 1976 p. 361
See also J.H.C. - Statutes - 1882 Vol. 2.

which the Act was in force (to 1888)¹ benefited no-one, not least the manufacturers of copper wire, since the effect of the Act not only dissuaded speculators but legitimate investors. The huge amount of wire expected to be consumed in power installations was thought to have been lost and investment in copper wire production suffered notwithstanding a very steady improvement in orders from the cable manufacturers. We may compare the United States, where the associated electrical industry was buoyant. Legislation similar to that experienced in England was not felt, and the American wire industry was to produce some 8,000,000 pounds of copper wire in 1894.²

In general, diversification was in the interests of any wire manufacturer;³ over-specialisation was uncomfortably risky and as such even those firms able to claim product specialisation did so in a specialised range of products. Thomas Bolton, for example, the Phosphor Bronze Company and Glovers' enjoyed positions as the foremost manufacturer of a particular product, but maintained no absolute reliance upon it. Additional factors were also instrumental in ensuring that no distinct single product industry (i. e. copper wire) would emerge alongside the general wire industry. Amongst these factors was the failure for all concerned to early establish standard types of wire and cable for the uses of power transmission. A bewildering range of shapes, sizes, gauges and combinations of transmission cable and conducting wire were being advocated in the last decade of the 19th century, therefore copper wire and ribbon manufacture had to contend with erratic demands and frequent production problems due to non-standardisation. As late as 1891, a controversy still raged concerning the comparative values of stranded and solid conductors and conductor geometry.⁴ Moreover, different cable manufacturers were apt to ignore the cost price of copper wire and impose a surcharge when working the wire into the design of a particular kind of cable. Whereas a probable purchase price of £75 per ton might be

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1 J.H.C. - Statutes - 1887, 1888 Vol. 2.

2 Journal of the Franklin Institute - third series, 146 1898 p. 158.

3 A good example was the manufacture of electric winding ropes used in collieries - electric signalling and mechanical traction were transmitted along the same cable. These cables utilised steel, iron, and copper wires. See Bucknall-Smith op cit p. 18

4 See Electrician - various correspondence in Vol. XXVI January 23rd, January 30th and February 6th 1891.

anticipated in estimating cable manufacturing costs, typically the conductor price could be elevated to as much as £100 "- to cover market fluctuations",¹ £15.00 of which was accounted for by "shop and administration" costs.² Since cable process costs were unique for any one type of cable, certain designs tended to penalise the use of one type of conductor as well as manufacturer. The wire industry could find little comfort in the hopes that a standard range of copper wire would emerge to satisfy all needs, especially when such variance was the basis of their customers' prosperity. The efforts of the British Wire Manufacturers Association,³ as representatives of the ferrous and non-ferrous wire manufacturers, had done a good deal toward establishing the Imperial Wire Gauge following years of exploitation, uncertainty and neglect due to the multitude of wire gauges in common use (see Chapter 8). But it could do nothing to hasten the establishment of a new electrical industry (which it was prophesised would provide a new prosperity for the wire industry); nor could it hasten the demise of traditional thinking of which one result was the buying of copper wire by weight. (Chapter 8). Nevertheless, it was not until 1899 that one of the copper wire industries' largest customers, the cable makers, realised that over-capacity and a failure to standardise was causing so serious a price-cutting war that total breakdown was imminent. It was later to be observed by L. B. Atkinson (Director of the Cable Makers Association 1918-1936) that:-

"- if steps were not taken to check this there might be serious breakdowns in the new public (electricity) supply - with the result that the public would lose confidence and the rising (electrical and cable) industry would receive a disastrous shock."⁴

As a result of consultations amongst the heads of the cable industry, a committee of manufacturers was formed and a little later, in 1899, the Cable Makers Association came into existence. To the benefit of the copper wire manufacturers, the C.M. A. devoted

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1 O'Gorman N. "Insulation on Cables" Jrn. Inst. Elec. Eng. Vol. 30, March 1901 p. 82.

2 Ibid.

3 The Association comprised, amongst others, of Johnson and Nephew, Rylands Bros., Nettlefolds Limited, The Whitecross Co., Edelston and Williams, The Shropshire Iron Co., Ramsden and Camm, Greening and Sons, Royston and Co., A. Rollason and Frederick Smith and Co. See Bucknall-Smith J. op cit p. 128.

4 Dixon H. N. op cit p. 233.

itself to standardisation in conductor sizes and other matters concerning cables. More especially, it agreed amongst the manufacturers a policy of standard prices for power cables. Such matters caused anxious moments in the wire industry and were yet further reasons for a measure of reluctance in beginning expansion programmes in the manufacture of copper conductors. The reliance on the electrical industry and conjointly the cable industry, neither of which was entirely stable even by 1900, could not justify an all-out investment in new copper wire mills.

The case of the C.M. A. is just one factor which determined that copper wire manufacture would develop somewhat more slowly than it might have. It cannot be said that if the development of the electrical industry in England had gone more smoothly then we would have witnessed the emergence of an organisation distinct from the general wire industry. No such development took place in the United States, France or Germany and as such there is no reason to think that the English industrial scene would have been different. The capacity for the production of copper wire changed and grew, yet the make-up of the industry manufacturing it did not; at least not markedly.

The wire industry was to a large degree at the mercy of apathetic smelters and the newly forming electrical industry, an infant industry which had not entirely found its direction. As such, the wire industry retained the safety of its traditions. It had, within it the capacity to produce copper wire and thus contained a characteristic manufacturing potential which could (or not) dominate, sub-serve or depart from, the wire industry as its fortunes willed. The constraints at the close of the 19th century were, it appears, such that little incentive existed for a secession by the copper wire manufacturers. Indeed, it is difficult to see how a rapid upsurge in industries based solely on copper wire could have occurred. Had the demand been overwhelming, it seems probable that the wire industry would have tried to respond from its latent capacity to provide volumes of wire of any one type, up to the capacity of its draw benches and annealing ovens. Alternatively, had the demand grown to enormous proportions so that the demand outstripped the ability to supply, then perhaps the result would have been the emergence of many new firms and the expansion of old ones, all basing their enterprise upon the manufacture of copper wire. In the event, no such overloading of the manufacturing capacity occurred.¹ As has been stated, the wire

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1 As is clearly shown by the maintenance of export levels. Vide Appendix 1.

industry tended toward consolidation rather than separation. The protection and safeguards that were the result of manufacturing flexibility and product diversification were reasons enough for the failure of a distinct autonomous copper wire industry to appear at this time. Only if monopoly had been possible, and diversification impossible, and if a totally new product with a new technology and its base had been needed, could a distinct industry have developed. At the end of the 19th century however, an industrial facility had appeared with an evolving capacity based on the needs of evolving technologies. The industry, apparently capable of servicing these needs, was not over stretched nor was it forced to establish new facilities or drastically change its condition at this time. The changes that were to take place came later in the early part of the 20th century¹ and were evolutionary rather than revolutionary. The growth of the electrical industry became rapid from the end of the 19th century - cable manufacturers turned to making their own wire, while the industry itself saw new firms established purely upon the production of copper wire.

Thus, copper wire was provided through the agency of an organised wire industry which supplied its markets by virtue of an inherent flexibility. The ability to contain excessive fluctuations in its trading, its rapid response to changes in its market were due, in part, to an over capacity in the wire industry which was dictated by a tendency to retain a traditional base. The ability to provide a surplus sufficient for export (see Appendix 1), demonstrates clearly the capacity for copper wire production. The technique of wire-drawing is essentially the same for all metals. It was this, more than any other factor, which determined that the copper wire industry would remain within the fold of the general wire-drawing industry until well into the 20th century.

In assessing those factors which governed the course and fortunes of copper wire and its attendant industries from 1750, it appears reasonable to include in any appraisal or conclusion, the following essential points. First, because of its basic nature copper wire,

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- 1 Non-ferrous metal manufacture only gained a representative body for research and representation in 1920, with the formation of the British Non-Ferrous Metals Research Association. See Cook M. op cit p. 190.

as with similar staple items, fulfilled a large range of needs in many quarters of manufacturing industry. As industry expanded, applications changed and grew, and the quality of copper wire changed also to accommodate the new requirements. New applications and the expansion of trade, controlled also the quantity of wire produced which in itself tended to determine the size and condition of the wire industry. Hence, the wire industry answered to its markets and the general economic growth from 1750. This could not have happened however, had wire not been such a basic material. There seems to be a starting point to every manufacturing and technological process and copper wire became the starting point in an ever-increasing number from the middle of the 18th century. The emergence of electrical science added to the range of traditional industries using copper wire and this was in itself, to be eclipsed by a greater appetite - electrical technology. In this application, copper wire became indispensable because it was at once economically and technologically the right and proper material with which to begin.*

The final evaluation therefore, must account for those factors which controlled the ascent of the manufacture of copper wire. They may be satisfactorily enumerated as follows:-

1. Copper wire and its manufacture flourished because it could be adapted to many diverse applications.
2. In adapting the quality of copper wire to fit one application, others tended to arise to exploit both like and similar qualities.
3. The application of copper wire to special purposes influenced the development of the manufacturing structure of the wire industry but:-
4. No entirely separate copper wire industry developed up to the 19th century because the diversification (of product range) in wire mills could be based upon a common process. This process was able to produce different wires, sheet and rod products without dependence on, or resorting to, large additions of plant.
5. In general, the manufacturers of copper wire were far from passive or inactive in their own progress and seldom let technological advances overtake them.
6. Whatever the delays and deficiencies in the quality and fitness of copper wire manufacture to suit it to electrical conductors, much was due to the failure of the copper smelters to keep pace with the needs of the new electrical technologies.
7. Because electrical technology, the principal market for copper wire from the 1880s, had followed a gradual development phase from the 1840s, the change in the wire industry was evolutionary rather than revolutionary.

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* "From what you write, copper wire was probably the most important material - scientific apparatus? - used in 19th century electrical science!"
"Yes - I think it must be the most under-rated contributor to the success of electrical science and technology". R.Y. to B.C. 1978.

One may be inclined to be critical as to the historical value of the above. The statements are not dramatic nor profound. They are nevertheless reasonable, simple and logical conclusions based upon the material presented throughout this work. Indeed, it might be argued that these conclusions are inevitable as a result of what has been said so far. However, in conceding this there is no suggestion that the issue is weak, tame and without historical importance. It is, and was, a commonly held belief that such a thing as a distinct copper wire industry grew up as an entirely separate enterprise and that there came into existence an autonomous group of companies who's mills turned out nothing but copper wire for the electrical industry. I have already mentioned Thomson ("a branch of copper manufacture has grown up in the course of these 26 years -") and his biographer, Gray ("Thomson's view prevailed and the result was the establishment - of Mills for the manufacture of high-conductivity copper - which is now a great industry.") and though we may be led to dismiss the increased output of copper wire at the end of the 19th century as the inevitable result of an expanding electrical industry, it would be quite wrong to let this imply that a new industry sprang up to provide for the increased consumption. Indeed, the non-emergence of a specialised copper wire industry at the end of the 19th century, and instead the prevalence of a general wire industry was, given the pattern of developments that controlled its state and condition at this time, expected if not inevitable. The appearance of an entirely separate organisation manufacturing only copper wire would have been not only contrary to general industrial change and the norm in industry practice, but particularly so in the context of late 19th century industrial patterns where the beginnings of incorporation and consolidation were recognisable in almost every quarter of industry and commerce. In the small concerns manufacturing wire in the wire industry's infancy and developmental period, it has been emphasised that diversification meant security, thus those operations allied to wire-making that provided marketable sub-products (i.e. tubes, sheet, rivets etc.) would not be neglected. In the larger, self-contained conglomerates, which manufactured

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wire, the same attitude was to be found but here the reasoning was taken one stage further, in that diversification not only ensured that all the processes attached to wire-making were exploited to their fullest potential, but that the product range could be as extensive as possible without calling on expertise outside its own capabilities. Whereas the smaller workshop would limit itself to making available only those materials, over and above wire, which were in themselves part of the wire manufacturing process, the larger concerns looked for ways of taking two or more such bi-products or sub-products and with some further processing realise an addition to their product range (netting, springs, barbed wire, brewing vats, galvanised net fencing, fencing rods, barrel hoops, marine rigging, bicycle wheel rims, spokes, trawling warps, axle spindles, baskets, tubes, rivets etc.).

In considering the non-emergence of a specialised, distinct copper wire industry, and in evaluating the importance of this in the history of technology, it is important to look at what might possibly have been the contrary situation; that of a very distinct industry based wholly on the manufacture of copper wire, without connection to the general wire industry and having no interest in providing any other product save copper wire. With the rise of electrical engineering it may have been expected that a plethora of companies would appear to act as a supply industry to the growing (but inconsistent) electrical market. Indeed, the lesson that this kind of thing is a (silent) truth in the nature of industrial change is to be seen in modern times, where many small firms have been borne of the expansion of principal industries such as motor engineering. In such circumstances the small companies survive, precariously, solely upon the manufacture of one component, a kind of industrial symbiosis. However, the sudden appearance of a host of copper wire mills, as imagined above, would have implied that prior to their coming into existence not only would copper wire supplies have been inadequate but that competition was negligible. Moreover, it would imply also that the electrical industry, as the instigator, had been meteoric in its growth. But, as we have seen, unlike the modern computer, silicon chip or motor engineering industries, the upsurge in power transmission, high speed telegraphy and telephony

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during the close of the 19th century depended upon a component which, with varying degrees of favour, had been common to traditional and electrical technologies for some 150 years. Hence, we can argue that the non-emergence of a distinct and separate manufacturing effort based on copper wire was due, in part, to the fact that electrical equipment manufacture, and power transmission, depended heavily upon a product that had practically completed its evolutionary stages of development, both technically and from the point of view of its industrial organisation and manufacturing technology. This evolution had seen its beginnings in the rise of telegraphy and in particular, submarine telegraphy where the transition stage had been accelerated. It was at this stage that the manufacturers of copper wire had first met the dictates of a new and demanding application for their products. The influencing of the wire industry by the growth of telegraphy, telephony and power transmission was achieved therefore against a background of cautious compliance on the part of the wire industry. This caution was not unfounded. The wire-drawers remembered that the infant electrical applications had been fickle, they heeded the lessons of the early telegraph systems where first copper and then iron or steel had been called for. Their product, even then, had been found wanting and better and better specifications had to be met. The rise of high speed telegraphy, telephony and, by the end of the century, electrical supply, now, once again, had begun to place emphasis on copper wire. The wire-drawers then had been faced with a undecided future from the early days of the telegraph. Indeed, the realisation even before this that diversification guarded against economic set-backs and poor trading had been an overriding factor amongst those forces which had controlled the organisation, composition, technology and policies of the wire industry. The move toward consolidation by the wire industry was part of the evolutionary path of a maturing, experienced industrial facility. The creation therefore, of an entirely separate single product industry producing only copper wire would have been, in terms of industrial evolution, regressive. In its infancy, the fragmented, loosely organised wire industry had operated to some large extent upon supplying a specific commodity

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to a few major outlets (shipping, textiles, for example) thus to return to the unpredictability of being nurtured by transient and uncertain markets, would have been foolhardy. Small trades, it is true, had been able to survive the longest in the manufacture of a single wire product because in such cases the wire was consumed directly at the point of manufacture (Sheffield Plate, for example). But the decline of the small trades which worked wire saw the rise of the large scale manufacturers who maintained their existence by incorporating flexibility into their manufacturing operations, setting themselves up as a general supply industry. In the provision of staple commodities such industries became the root of the ascent of 19th century industry. In such circumstances the appearance of a separate copper wire manufacturing facility would, as we have noted, be anomalous. Had such a thing taken place it would have meant that the consumption and demand for copper wire had stimulated, through the consumer, a demand for a product unavailable; or beyond the capacity of, the established supply sources. Moreover, the implication would be that there had come about a demand for a product with a definite technological and manufacturing difference which the general wire industry was disinclined or incapable of meeting. However, as we have seen, far from being disinclined to meet the challenge of the needs for new grades of copper wire as it had been, the wire industry was, by 1877, beginning to make available new and better types. All the while, however, it maintained restraint in turning over ever more manufacturing capacity to the uncertainty of the new electrical industries. In such a climate therefore, only a few specialist groups could risk the enterprise of setting up new mills to make copper wire as the sole product. Even then, as with the Phosphor Bronze Company, the product was specialised by virtue of shrouded processes used in its manufacture and was protected against unfair competition by patents. Even so, diversification in this company was normal policy.

It appears that a set of conditions can be created in consumer industries which tends to suppress the opportunity for risk taking by new supply industries. Although the scarcity of a product or commodity can stimulate the speedy generation of new

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factories to meet increasing demand, this never became the case for the manufacture of copper wire after the middle of the 19th century. The established wire mills had early on limited their risk by product diversification and their very existence and evolving manufacturing capacity had eliminated to a great extent the likelihood of large numbers of new companies springing up to supply a market already adequately met. Indeed, the circumstances began to change markedly in that whereas the consumers of copper wire had, up to the late 1870s, influenced the quality and production of copper wire, from this time on the wire industry itself began limited risk-taking ventures of its own by making available better copper wire; this, in an attempt to stimulate its markets and consumers. This attitude was based upon the realisation on the wire industries part, through such people as Doolittle, Bolton etc., that better product development was a minimal risk venture and entailed little chance of disturbing the equilibrium that the general wire production and product diversification maintained. On the contrary, it did nothing but hold out promise for better business and increased markets with the likelihood that should nothing come of it, the cost could be absorbed. The consumer therefore, was beginning to lose ground in being able to influence a stable industrial capacity which was now consolidating its strength and ability to control its own development and direction. Simple ideas concerning supply and demand were changing. The wire industry had a strong position tempered by much experience, expertise and a cautious eye to markets. It was able to answer to fluctuations in demand with convenient ease and its destiny was, to a great extent, in its own hands.

In analysing such a situation we see that the simple equation which linked supply and demand had therefore almost given way in the wire industry by the final third of the 19th century. Copper wire had become part of the range of commodities identifiable as staple components of a firm industrial and technological effort. The equations that balanced its future dealings from the 1870s tended to be the reverse of those that had been so important in its past. This means that a stable wire industry

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was unmoved in the face of unstable demands for some of its products and it was strong enough to attempt to influence the condition of its markets. Indeed, it appears that the wire industry was to be inclined to make efforts to equalise the entire supply/consumption system. Changes which affected the system (sudden preferences for one type of wire or another, economic fluctuations, transient demands etc.), became within the control of the wire industry, which, having evolved through similar difficulties in its past had shaped itself to have the latent capacity to manage by means of market stimulation or simple stock-piling actions. The wire industry therefore, had matured into a force able to adjust the system to some extent so as to temper, if not annul, the effects of the changes it experienced in trading and demand. Indeed, it was taking tentative steps in an attempt to provide grounds for technological progress, which, if successful would make for an improved and much more stable trading climate. In short, therefore, a form of Le Chatelier's principle¹ appears to find some expression in the condition of the wire industry and its markets at the close of the 19th century. Hence, given the conditions and circumstances which existed throughout the 19th century to control and modify the development and uses of copper wire, and the growth of the general wire industry, we find that the failure of a distinct copper wire industry to emerge was not contrary to the economic and technological factors which governed the growth and expansion of wire manufacture during that time. We may conclude therefore, that the important issue here is not that a distinct copper wire industry failed to emerge, but more importantly, that such a thing could not have happened.

Critics may view the above as just so much worthless wordage - what value is there in knowing this? Can the discovery of obscure truths only be justified on the basis that all knowledge has value? Certainly, there is something greater here than a revelation which merely adds to our store of knowledge another, possibly negative, aspect of industrial change. It lies in the plain fact that in failing to include the necessity of an established wire industry in the development of electrical engineering we are without a major factor in its evolution. The assertion that a separate copper

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1 "A system in equilibrium if subjected to stress will tend to react in such a way as to adjust itself, and annul, as far as possible the effect of the change." After Henri-Louis Le Chatelier (1850-1936).

wire industry could not have emerged, and that indeed the general wire industry did not conflict with the particular laws of industrial change which controlled its evolution, tells us why copper wire manufacture was, throughout the 19th century, imperceptive as an autonomous and distinct manufacturing concern. This, in turn, says much about the reason the manufacturing effort behind copper wire is often discounted, or de-emphasised in the development of the electrical industry - its concealment in the general wire industry failed to give it prominence or any firm identity. This, therefore, has significance in the history of the rise of the electrical industry which must, in future, be more fully appreciated and accounted for. A watchful, weary and business-like attitude borne of many years of changing fortunes produced a wire industry circumspect and cautious, but nevertheless stable. The structure that it presented was a firm rock for the expansion of the electrical supply industries of the advanced nations. Without this acknowledgement our histories are incomplete.

APPENDIX 1

TRADE STATISTICS - THE EVIDENCE FOR THE CONSUMPTION
AND PURCHASING OF COPPER AND COPPER WIRE

Perhaps the most vivid illustration of the ascendancy of English copper wire as an indispensable commodity in manufacturing industry is to be seen in the available export trade statistics. When represented graphically, the numerical information provides a clear representation of the progressive performance of copper wire in world markets and indicates the increasing manufacturing capacity of the English mills, for the beginning of the 19th century. Figure 1, which covers the export of copper wire from England throughout the first seventy years of the 19th century, displays a clear trend toward greater consumption from the 1840s culminating in a 500% increase in consumption (for the period 1850-1860) over the previous decade (a period which in itself represented a 350% increase over the preceding ten years). This trend is better shown in Figure 2, which is derived from figures achieved by taking the mean value of exports over consecutive five year periods. This is likely to be a more truthful representation in any case, since it allows for "overlap" of annual quotas and "short years" in the customs house figures. Some explanation of the marked increase in exports from the middle 1840s may be gleaned from the substantial decrease in the price of English copper wire during this period - as the price of copper came down (by some 30% between 1840 and 1853) so the cost of English wire fell accordingly, making the English produced wire the more attractive and competitive on foreign markets. The comparative price variations of English copper and English copper wire for the period are shown in Figure 3. Here the close relationship between copper prices and the cost of copper wire is seen to be not entirely inseparable, but very closely aligned. Thus, exports generally reflected the price of English copper which tended to control the price of copper wire. Huge orders, extraordinary for any period, sometimes occurred when English copper was very cheap. The period November 1852 to August 1853 saw unprecedented orders of 85 tons of copper wire from Denmark,¹ and 20 tons from the

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1 Parliamentary Papers J.H.C. Vol. XCIX 1853 (903) p. 151.

East Indies¹ - this was a time when English copper had just experienced a slump in prices. From 1850 to 1852 copper was selling at its lowest value since 1800; at about £85 per ton.² The dependence of copper wire exports on the price of copper is expressed well in Figure 4. Severe fluctuations in the price were resultant upon the availability of copper which could depend much upon prevailing political and economic conditions. English smelters gained new impetus in the 1840s when the price of Sicilian Sulphur rose from £5 to £14 a ton - the importance of sulphur in the manufacture of sulphuric acid could be diminished by the production of sulphuric acid from copper pyrites. Increased copper smelting based upon copper pyrites was able to provide a sulphur by-product for the production of sulphuric acid.³ A consequent reduction in the price of copper continued from the 1840s, but annual price fluctuations were felt for a variety of other reasons. The steady decline in the cost of copper was halted in the 1860s. The fear that a major source of copper ore might be lost, sparked off an immediate price increase in 1865, when it was thought that a war between Spain and Chile would affect Chilean ore supplies to England. Between the 17th October 1865 and the 15th November of the same year copper rose in price by £30; from £86 per ton to £116 per ton.⁴ However, upon the actual declaration of war, and as hostilities commenced, prices of English copper began to fall - speculators, it was said, had pushed up the price but caution and foresight on the part of consumers (many of whom held good stocks of copper) influenced the reduction in prices.⁵ As shown in Figure 4, the rise in the price of copper during the 1860s was reflected in a levelling off of copper wire exports as the price of wire was maintained. The consequent reduction in the average price of copper after the middle 1860s is mirrored in the steady gain in the quantity of copper wire exported after this time. Indeed, throughout the entire history of the production of copper wire as an article of commerce, it has answered to the variations

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1 Ibid.

2 Timmins S. op cit p. 259.

3 Schofield M. A Remarkable Century - op cit p. 26.

4 Timmins S. op cit p. 258.

5 Ibid.

in the selling price of copper and only at the end of the 19th century were the wire-drawers able to stabilize wire prices through better control over the efficiency of production method and market variations. Figure 5 represents the variations in the general selling price of copper wire throughout the period 1569-1900. The selling price never appears to have exceeded 1s.6d. per pound. The selling of copper wire by weight was customary right up to the end of the 19th century and appears to be a tradition which was maintained irrespective of the quantity, or the gauge of wire being produced. However, variations as a function of gauge have been noted but they do not consistently reflect the quantity, quality and length of wire being purchased. In general, the buyer purchased a certain weight of copper.¹ As Figures 3 and 5 show, the price of copper wire tended to decline steadily from the 1840s, and as pointed out above, this reflected the overall decline in the cost of copper. The various factors of any significance which contributed to the variations in copper prices, and hence wire prices, are presented in Figure 6. The improvement in English copper supplies from Elizabethan times to the start of the Civil War resulted in a reduction in the selling price of wire - the decay and disorganisation in the English copper industry following the Civil War led to high prices for wire which was a trend maintained up to the beginning of the 18th century. Over the 100 years from 1700 to 1800, the price of copper and copper wire declined with the growing political and economic stability and increasing industrial activity encouraged mining, smelting and wire-drawing. It was, however, the beginning of the Napoleonic wars, which, in the consumption of huge amounts of marine copper, and the disruption in European trading, forced up the cost of wire. Prices remained high until 1830 but then decreased steadily until the high volume production of electrical conductors at the end of the 19th century allowed the cost of copper wire to fall dramatically. It was only with the advent of the large scale production of wire for electrical, telegraphic and telephonic applications that the wire-drawers felt themselves able to improve their traditional price margin between the cost (per ton) at which they bought copper, and the price (per ton) at which they sold wire (Figure 7). For the first half of the 19th century, the margin remained at approximately 30%; sufficient to absorb production costs and to maintain a satisfactory profit. By the latter third of the century

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1 For further comment on this aspect Vide infra Ch. 8 p. 204.

however, the margin had grown to some 44%. This may be explained by assuming that the cost of improved high efficiency wire-drawing equipments, and the apparatus for electro-welding and electrolytic refining had to be financed. But though this may well defend the peak difference, as seen in the middle 1880 s, the increased marginal difference in the profit margin between that time and 1900, can only be seen as a handsome dividend for the copper wire-drawers. We may presume that a higher demand for copper wire, as experienced in this period, supported a higher price than otherwise might have been had supply and demand been more in concert. Nevertheless, by 1900 the price of copper wire at approximately $7\frac{1}{2}d.$ ¹ per pound was at an all time minimum.

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- 1 Bright C. op cit p. 214. According to O'Gorman (Jrn. Inst. Elec. Eng. 30, 150, 1901 p. 644) some 8% of the cost of copper wire was accounted for in the drawing of the wire.

SOURCES:- Evidence for this chapter was obtained from the following sources -

1. Brown N. & Turnbull B. A Century of Copper -. Effingham Wilson 1899 - 1900.
2. Timmins S. Birmingham and the Midland Hardware District .Robert Hardwicke 1866.
3. Window F. R. "On the Electric Telegraph" Proc. Inst. Civ. Engs. IV, 1851-2 p. 365.
4. The Penny Encyclopaedia Vol. 4 p. 506 - The Society for the Diffusion of Useful Knowledge - London 1838.
5. The Cyclopaedia of Useful Arts and Manufactures Editor -.Charles Tomlinson, Virtue, London 1866 p. 441.
6. Record of the International Exhibition -.London 1862 p. 217.
7. British Parliamentary Papers - the 53 volumes (1817 - 1871) containing accounts and papers covering imports and exports of British manufactured goods. See general index for accounts and papers 1801 - 1852, 1852, 1853, 1853 - 1868 and 1869 - 1870. In particular see:-

1812	(115.) (116.) X. 29. 33.
1813-14	(259.) XII. 227.
1817	(188.) (189.) XIV. 277. 279.
1818	(149.) XIV. 171.
1819	(230.) (231.) (232.) XVI. 199. 203. 207.
1820	(24.) (25.) (26.) XII. 91. 95. 99.
1821	(183.) (184.) (185.) XVII. 95. 99. 103.
1822	(155.) (193.) (388.) XXI. 297. 301. 305.
1823	(160.) XIII. 429.
1824	(130.) XVII. 153.
1825	(143.) XVII. 159.
1826	(144.) XXII. 151.
1826-27	(210.) XVIII. 23.
1828	(214.) XIX. 267.
1829	(144.) XVII. 321.
1830	(286.) XXVII. 147.
1831-32	(420.) XXXIV. 293.
1833	(361.) XXXIII. 229.
1834	(234.) XLIX. 41.
1835	(166.) XLVIII. 35.
1836	(206.) XLV. 19.
1837	(258.) L. 23.
1837-38	(342.) XLV. 29.
1839	(232.) XLVI. 51.
1840	(282.) XLIV. 25.
1841	(257.) XXVI. 131.
1842	(217.) XXXIX. 437.
1843	(237.) LII. 59.
1844	(225.) XLV. 87.
1845	(in 300.) XLVI. 73.

1846		(in 396.) XLIV. 127.
1847		(in 449.) LIX. 47.
1847-48		(359.) LVIII. 319.
1849		(in 318.) L. 453.
1850		(457.) LII. 251.
1851		(476.) LIII. 345.
1852		(462.) LI. 453.
1853	1852-53	(903.) XCIX. 151.
1854		(310.) LXV. 401.
1855	1854-55	(299.) L. 395.
1856		(257.) LV. 341.
1857		(102, Sess. 2.) XXXVIII. 243.
1858	1857-58	(151.) LIII. 441.
1859		(11. Sess. 2.) XXVII. 299.
1863	1864	(253.) LVIII. 113.
1864	1865	(275.) L. 719.
1867	1867-68	(273.) LXIV. 141.
1868	1868-69	(239.) LVI. 15.
1869	1869-70	(240.) LXI. 299.
1870	1870-71	(255.) LXII. 53.

Trade/export returns were not made for the years absent in the above list. For other aspects of copper trade, debates and evidence to select committees, see British Parliamentary Papers and Journal of the House of Commons for period 1799 - 1900.

8. Evidence for copper wire prices between 1569 and 1898 were obtained from the following sources:-

1569	10d.	Collingwood W. G. "Elizabethan Keswick" London 1912 p. 33. See also Hamilton op cit p. 355.
1636	8d.	Danby G. British Patent No. 96 4th March, 1636.
1640	1/3d.	Hamilton H. op cit p. 52.
1697	1/5d.	Houghton J. A Collection for Improvement of Husbandry and Trade . No. 257 op cit.
1814	1/6d.	After Boulton - found in Hamilton op cit p. 367.
1837	1/3 - 1/6d	Mechanics Magazine 1837 p. 319. op cit. Also Francis G. <u>Annals of Electricity</u> 2, 1838, 396.
1852	1/-	Window F. R. "On the Electric Telegraph" Proc. Inst. Civ. Engs. IV 1851-2 p. 365.
1883	9.3d.	Bolton A. S. Proc. Inst. Civ. Engs. LXXV, 1883 p. 100-101.
1898	7.8d.	Bright C. Submarine Telegraphs . op cit p. 214.

The prices quoted above refer to the price of copper wire per lb. (or as close an estimate thereto as possible).

APPENDIX 2

AN EXAMINATION OF SOME EARLY EXAMPLES OF COPPER WIRE DUE MAINLY
TO FARADAY

Through the interest and kindness of Professor R. King of the Royal Institution, the author was provided with some examples of early copper wire, known to have been used by Henry Cavendish (1731-1810) and Michael Faraday (1791-1867). The samples were obtained with a view to determining the quality of early copper wire (of known provenance) so as to establish material proof in support of written historical evidence as presented in this study.¹

Because of the fame of both Faraday and Cavendish, much effort has been made to preserve the residue of their experimental apparatus. Included amongst those items which have survived from the equipment used by both scientists, are lengths of copper wire which can, with some measure of certainty, be placed as to their period of use. However, the manner in which the wire came into their possession has not, as yet, been established. Though the apparatus incorporating the wire can with confidence be attributed to Cavendish and Faraday (thus providing the period and manner of application) the ultimate source and origin of the copper wire (in terms of its date and place of manufacture) remains in doubt. Nothing whatsoever is known about the source of Cavendish's apparatus - he bought cheaply and lived a frugal and isolated life. It is interesting to note that the copper wire in his possession was used repeatedly and apparently seldom replaced; copper wire with many knots in it once acted as a basis for experiment to see whether the knots reduced the strength of an electric discharge when compared to a discharge through wire with no entanglements.² Faraday's copper wire, though surviving in greater amounts to this day, has no history beyond Faraday himself. Records at the Royal Institution make no mention of the purchase of copper wire, and it is believed that the principal source for the wire used in Faraday's time would have been through the agency of the Royal Institution's instrument maker, Mr. Newman.³ Doubtless, his responsibility would have included the

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1 Vide Chapters 5, 6 & 7.

2 Vide infra Ch. 5 p. 139.

3 This point was suggested by Professor R. King, to whom the author is indebted for much guidance in this area.

supply of iron and copper wire, but beyond this nothing more can be said. (The fact that the note book of Faraday records nothing about the purchases or acquisition of wire, suggests that he took no responsibility for it). To place the wire as having been manufactured between 1800 and 1820 does not seem to be unreasonable, little would have been purchased by the Royal Institution in the 1820.s when it experienced severe financial difficulties ("We are living on the parings of our own skin", Faraday told the managers),¹ and since all the wire examined was in use by 1830 it is clear that its manufacture antedates this time. It is fairly safe then to presume that the wire used by Faraday was made in the first 20 years of the 19th century. Indeed, three samples can be dated at no later than 1821, since it is known with certainty that Faraday was using the copper wire in experiments on magnetism, and accordingly he recorded it in his notebooks. The samples of wire ascribed to Faraday were cut from the many coils and toroids preserved in the Faraday Laboratory at the Royal Institution. Within the same laboratory resides one piece of apparatus known to have been amongst the equipment used by Cavendish. Thus the sample of wire attributed to Cavendish is a cutting taken from some copper wire found on the end of the tray suspension of a chemical balance (circa 1770). The samples are viewed individually as follows:-

Specimen A1 - Wire from a double wound coil on a cardboard former. Six windings of copper wire and six of iron. The copper is approximately No. 12 B.W.G. This is described in Faraday's Diary for September 12th 1831 as having then been recently made. It was experimented with on September 24th 1831 in Faraday's researches on electro-magnetic induction which he first discovered on August 29th 1831.

Specimen A2 - A single wire, uncovered, bent into a square figure of eight. Wire diameter .050 inches (approximately No. 18 B.W.G.). Date uncertain, probably used in the investigation of magnetic fields. Probably after 1831.

Specimen A3 - Section from Toroidal coil. Insulated wire of diameter .03 inches (approximately No. 20 B.W.G.). Almost certainly used in researches on electro-magnetic induction.

Specimen A4 - Bundle of six coils wound on square iron cores. Insulated wire of diameter .05 inches (approximately No. 17 B.W.G.). Could have been used in work on electro-magnetism. Circa 1821.

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1 Kendall J. Young Chemists . Scientific Bookclub 1939 p. 70.

Specimen A5 - Coil wound on musket barrel. Dated with some certainty at October 17th 1831. Uninsulated wire of diameter .045 inches (approximately No. 19 B.W.G.). Used in researches on electro-magnetic induction.

Specimen A6 - A loose coil of insulated wire. Unidentifiable but believed to have been made by Faraday. Wire diameter .104 inches (approximately No. 12 B.W.G.).

Specimen A7 - Sample from the winding of an astatic galvanometer. Circa 1832. Covered wire of diameter .017 inches (approximately No. 27 B.W.G.).

Specimen A8 - Flat spiral, covered wire, mounted on card. Wire diameter .104 inches (approximately No. 12 B.W.G.). Used in examination of magnetic curves (i.e. lines of force). Circa 1821.

Specimen A9 - Small coil completely enclosed in calico except for the ends of the wire. Wire diameter .05 inches (approximately No. 17 B.W.G.) Used in examination of magnetic curves (i.e. lines of force). Circa 1821.

Specimen A10 - Small end stub of wire used to suspend balance pan on the Cavendish balance.

Physical Parameters

Two paramount objectives were to be satisfied in the chemical and electrical analysis of the specimens. The accurate assay of each sample would provide interesting data as to the probable source of the copper from which the wire was made, and would give additional information concerning the variants in smelting techniques common to copper prepared for wire making. In addition, once trace impurities in the copper had been accurately established, the relative conductivity of each sample (as referred to pure copper) could be predicted by means of Matthiessen's Rule, which accounts for the additive effect of impurities (and other physical conditions) which influence conductivity. Such information would serve to support the direct electrical measurement of the copper samples by means of a numerical comparison, an exercise justified by certain doubts surrounding the limitations in any procedure of electrical measurement intended to establish directly the conductivity of exceedingly small and irregular copper samples. The importance of performing such tests lies in the ultimate confirmation of evidence derived from historical investigations. The approach in any such series of physical measurements is further complicated by the fact that two practical standards exist for comparing the conductivity of a copper specimen. Under the terms of the 1913 International Annealed Copper Standard, pure copper is expressed in terms of a mass-length (resistivity) standard such that a wire of mass one gram drawn to a length

of one metre shall exhibit a resistance of 0.15328 Ohms providing the copper is absolutely pure.¹ This value is based upon Matthiessen's Standard (1860) and though accepted in 1913 as invariable, it has since been recognised as being some 2% higher than the best experimental results suggest (i.e. 0.1508 Ohms per gram-metre). The adoption of the rationalised m.k.s. system provided a copper standard which was based upon volume-resistivity such that the resistance of pure copper was determined by evaluating the resistance between two faces of a centimetre cube of pure copper (1.7×10^{-6} Ohms per centimetre)² giving a resolved value of 1.7×10^{-8} Ohms/Metre.

For any sample of copper the resistance can be established in terms of the standard volume-resistivity by evaluating the formula:-

$$R = \frac{\rho l}{a} \dots\dots\dots 1$$

where R equals overall resistance, a the cross-sectional area of the conductor, l the conductor length, and ρ the specific resistance. Hence the resistivity ρ may be found by transposing the formula above viz:-

$$\rho = \frac{R a}{l} \dots\dots\dots 2$$

For the same sample, resistivity in terms of the mass-length standard requires substitution of values in the formula:-

$$\rho \left\{ \Omega / (g) (m) \right\} = \frac{R S_w}{R_p L} \dots\dots\dots 3$$

Where R is the measured resistance, S_w the sample weight, R_p the path length over which the resistance is measured and L is the overall length of the conductor.

Whereas a volume-resistivity standard demands a precise knowledge of the cross-sectional area of a conductor (and hence the diameter of a wire), and since this value must be assumed constant (which for the irregular samples in question it is not), then the use of a mass-length standard is attractive because it can ignore this limitation. The mass-

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- 1 Ricksecker R. E. "Copper and its Alloys" Kirk Othmer Encyclopaedia of Chemical Technology 2nd Edition Vol. 6 p. 186 (23 Vols) J. Wiley 1969.
- 2 Ballantyne D. W. G., Lovett D. R. Dictionary of Named Effects and Laws. Chapman Hall 1976 p. 211. Also Clark J. B. New Physical and Mathematical Tables. Oliver and Boyd 1957 p. 56.

length standard requires no knowledge of conductor diameters in the calculation of relative conductivity. Assuming g is constant, sample weight reduces the sample mass into the same dimensions used in the standard itself i.e. the standard mass-length resistance expresses mass in terms of the force exerted by a mass of one gram due to gravity.¹ Once the overall sample length is ascertained, the ratio of mass to length allows for conductivity to be resolved in terms of a mass-length standard. This requires only the additional factor of resistance per unit length to complete the equation.

It should be noted that since both the aforementioned standards refer to pure copper, a conversion factor can be generated which relates one standard to the other, such that to convert Ohm/metre $\times 10^{-8}$ to Ohm/gram metre a multiplication factor of 11.3746 is used. The converse requires multiplication by 0.08791518. It follows from this observation that relative conductivity based upon one standard can be converted to the other - a factor which in this investigation was encouraging, since in the initial stages of electrical test it was not clear which approach (in sample testing) would demand procedures which were experimentally unrealistic. It was clear from the small size of the samples that difficulties were likely to be encountered in achieving precise values for those parameters required by each standard. If ultimately, only a volume-resistivity value could be accurately resolved a mass-length equivalent could easily be calculated; in addition some measure of control was available if two values based upon different standards, but derived from the same sample needed confirmation. The two values would have to satisfy, within acceptable limits, the computed conversion factors. Thus, it was expected that with correct judgement and proper test facilities relative conductivities could be assessed. Such knowledge would indicate the quality and the variability of copper conductors available to Cavendish and Faraday.

Preliminary Survey

The investigation into the condition and properties of the wire specimens began with a visual inspection of the surface features of each wire cutting. The irregularity of the specimens precluded the constant use of a medium power optical microscope, and for

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1 This ignores the relative changes in density due to variations in impurity concentration. Such variations were found to be, and treated as, negligible.

initial observations a low-power hand lens (x10) and manual orientation of the samples was found to be much more convenient. Where an interesting condition was noted the sample was removed to the bench microscope and the sample in question inspected after being mounted upon a slide. The use of this procedure made for economy of time and effort, the microscope being reserved for confirming, or not, as the case may be, an apparently interesting observation noted through the use of the hand lens. Once a condition had been identified as interesting evidence, then a permanent visual record was provided by electron-micrographs. The same slide upon which the specimen was correctly orientated could be taken from the optical microscope and fitted directly into the electron-microscope.

The surface quality of the samples throws light upon an important aspect of early copper wire making. The appearance of the various surfaces at medium magnifications has disclosed that during the time of its manufacture, much of the wire was maltreated. Plates 1a - 10 are electron-micrographs¹ of some of the samples made available to the author and provide clear evidence of the indifferent way much of the wire was made. In addition, as in the case of sample A6 and A9, there is some indication as to the exact method of production.

Electron-micrographs were taken at magnifications of x20, x100 and x200. The most productive magnification was generally x20 and in the case of Plates 2, 3, 4, 5 and 9, surface striations of a severe nature are visible. Deep striations

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1 I am grateful to Mr. F. Hunt for much valuable work in this area. Many hours of painstaking visual inspection of the whole of the surface area of each individual sample using a hand lens and microscope resulted in the author and Mr. Hunt finding much valuable evidence. The electron-micrographs were produced by a Cambridge electron-microscope, model 1969.

are indicative of a poorly formed draw-plate, the die surface being worn and badly grooved. This is particularly evident in Plates 4 & 9 and very noticable in Plates 2, 3 and 5. Of particular interest however, are Plates 6 & 9, which by extreme good fortune exhibit the remains of some indentations caused by wire drawing tongs. The serrated face of drawing tongs, either in hand drawing the wire or in self-acting drawing machines using grips (vide Chapter 1, 3), appears to be the cause of these marks. There is every indication that the wires were re-drawn at least once after the markings were produced; no displaced material surrounds the cavities, and their distance from one another implies that some extension has taken place so spreading the marks. Visual inspection of the specimens at low powers of magnification resulted in the discovery of a number of indentations similar to "crows feet" on various parts of the surface. Once again, this is strong evidence of tong action, where a serrated edge has "dragged" back some surface material. It should be noted that Plate 1b displays the remains of silk insulation which along with wrapped cotton was a common method of insulating conductors.

Chemical and Electrical Tests

Of the various samples attributed to Faraday and Cavendish, few exceeded five centimetres in length. Indeed, some of the specimens were exceedingly short and of a fine gauge (in particular sample A7 (Faraday) and A10 (Cavendish) neither of which was longer than 7mm) and in view of this it was at first concluded that the difficulties likely to be encountered in determining the specific resistance/conductivity of these very short samples would demand unacceptable amounts of time, elaborate and sophisticated test facilities and innovative techniques necessary to prepare and present samples for electrical test.

Initially, physical measurements upon the samples appeared to be restricted to chemical analysis. Sufficient material was available for assay in all cases and consequently the author determined that the cuttings be committed to chemical analysis and that for electrical tests the necessary data could be expected by resorting to measurements of the original "mother" lengths. It was hoped that the longer lengths of wire, if accessible, would resolve the problem through the

promise of simpler measurements and thus ultimately more precise results. Extended lengths, and consequently higher resistances, were expected to eliminate the need to resolve very low orders of mass, length and resistance; parameters necessary in computing resistivity in terms of both previously mentioned standards. It was soon realised however, that any exercise intended to measure the resistance, length and weight of the original coils etc. was itself impracticable. In many cases obtaining such data would have necessitated the unwinding or dismantling of valuable specimens - an act unlikely to conserve the original form of these precious items. Indeed, such procedures offered no guarantee of meaningful results; wire, when unwound is often kinked and presents a difficult task in measuring length. In some cases the wire could not be isolated and in others the wire was insulated so that weights could only be estimated. Furthermore, consistent with wire of such an era, diameters varied considerably throughout a length.¹ In short, the proposed exercise was abandoned in favour of proceeding with an examination of the small samples whatever the associated problems. Chemical analysis would be delayed until the electrical tests had been satisfactorily concluded.

An extremely difficult and time consuming series of measurements, requiring the adoption of ingenious and innovative methods,² was accomplished with great care by Dr. R. Yorke in the University of Southampton.³ An equally careful assay was undertaken by Dr. Ovenden of the same University, using Atomic Absorption Photometry techniques similar to, and with the same resolution as, that used in estimating trace concentrations of elements in sea water. The process compares well with the best analytic techniques currently available and is capable of estimating impurity concentrations quantitatively to a very high order of accuracy.

Through close attention to experimental method, and the use of equipment able to resolve with high accuracy the required electrical properties of the specimens (length,

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- 1 Thoughts on achieving a mean value which was statistically meaningful was abandoned when it was realised that many wires were insulated, and in any case, the number of readings in certain instances was unacceptably high - and in other cases incapable of being obtained at all.
- 2 The nature of all these experimental methods will be discussed in detail as the subject of a forthcoming paper by the author and Dr. R. Yorke.
- 3 As a matter of coincidence in the Faraday building!

resistance path length, weight, diameter and density) Dr. Yorke determined the specific resistance both in terms of the mass-length (resistivity) standard and the volume-resistivity standard for each sample. Those samples which were considered to be the most likely to cause doubt (with regard to each parameter) due to their small size, were repeatedly tested in an effort to eliminate error. Table 1 shows all the test results and the range and order of the trace impurities revealed by assay. Sample resistivities predicted upon the basis of assay, and conductivities relative to the I. A. C. S. standard, are also shown.

The variance in impurities and impurity concentration is of note, there is little similarity between any two pieces of wire. Indeed, it was this point which masked the abnormally high level of lead and tin in sample A5, a factor which was not explained until it was realised that a varnish coating and years of atmospheric deposition had served to obscure a layer of solder on the sample surface. The wire had clearly been "tinned" at some time to facilitate easier soldering, and at some time afterwards varnish had been applied. Sample preparation prior to assay had failed to eliminate the effect of the lead tin alloy due to residue, and diffusion into the copper. Only after electrical testing had established a value for specific resistance inconsistent with that expected from the affects of the trace impurities was the sample re-examined. Such predictions had in all other cases been found to be remarkably close to the measured value, a pleasing result since the predictions were based upon Matthiessen's Rule which accounts for the collective effect of each elemental impurity upon specific resistance viz:-

$$\rho_{\text{Tot}} = \rho_{\text{imp 1}} + \rho_{\text{imp 2}} + \dots + \dots + \rho_{\text{imp n}}$$

The individual affects for elemental impurity concentration upon the resistivity of copper were taken from the authoritative article "Copper and Its Alloys" to be found in Kirk-Othmers Encyclopaedia of Chemical Technology (op cit).

This simple exercise established the accuracy of forecasting the resistivity due to impurities. Little effect appears to be introduced by other factors such as crystalline defects in the copper. Such contributions to the specific resistance as might be made by such factors is negligible when compared to that of elemental impurities. The comparison between predicted and measured resistivities is shown graphically in Figure 1. The

excellent correlation between the two is in general striking. A disparity in sample A1 between the measured and predicted values was later explained as being due to a high level of arsenic not found to the same degree in the other samples.

In general, the samples exhibit a range of conductivities and impurities not unexpected. Chemical analysis as provided by atomic absorption shows clearly the extreme variations in the purity of the copper wire; a result which was as stated, not unexpected, but surprising in aspect due to the inconsistency of any one sample with another. No two appeared to be entirely complimentary. Such variation can be explained only by presuming that the smelters, who processed the ore which eventually led to the production of the wire were either incapable of reproducing the same quality in different smelts, or, there were a number of smelters involved, all able, or unable, to produce a consistent level of purity. Added to this is the element of variability in the supply of copper ores (at this time mainly British) each with its characteristic range of impurities.¹ The Faraday sample appear then to reflect a typical standard of purity for the time, a standard which was quite undemanding. The Cavendish sample in complete contrast, was found to be exceedingly pure. The Cavendish sample (A10) exhibited very low concentrations of trace impurities, being some 99.9% pure. If we could choose to disregard the iron concentration as an alloyed impurity, then the sample would approach the I. A. C. S. standard of conductivity. However, on the presumption that the iron was not surface deposited, and originated in an oxygen-free copper smelt, then the sample in question (which was very small and could not be measured with any confidence) would, at best, have achieved only 28% of the I. A. C. S. rating. This would have been equal to a resistance of some .54 Ohms per gram metre as compared to .15328 Ohms per gram metre at 20°C; the high yield of iron, being the prominent trace impurity affecting conductivity. Due to the uncertainty in measuring this sample it must be concluded that the predicted value for specific resistance is probably the more correct. Nevertheless, the purity of the sample refutes the result and the surprisingly low level of elemental impurities is an

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1 For further comment on this - vide Ch. 9 p.208 and Ch. 7 p. 180.

unexpected discovery, especially in the light of the predictably poor showing in the Faraday specimens. The contrasting result is worth a brief comment. It has been suggested by the author that the Cavendish balance may have been provided with new suspension wires at the close of the 19th century when copper wire of higher purity, than hitherto available, could be had. This possibility was viewed by Professor King as possible, but improbable since there is no evidence to suggest that any such exercise was carried out. The residual deposits of soot and dirt etc. on the wire denies its introduction to the balance at the beginning of the 20th century and suggests that it is much older. It is concluded then, that the wires are as original. On this basis, it must be considered extraordinary that Cavendish left as a legacy, a rare example for his time - a specimen of almost pure copper.¹

The Faraday specimens (excluding the iron wire which was 99.9% pure) are remarkable in themselves for their variations in impurity content. All contained silver and zinc in various proportions. Both elements are to be expected since silver is consistent with many copper ores, and zinc was closely aligned to brass making, an area where copper working was also a common practice. In all cases, there is a high level of nickel, lead and tin and these remain the principal impurities responsible for the generally poor conductivity of the Faraday samples.² The best example (A7) with regard to conductivity, gives a value of 99.5% of the modern I. A. C. S. standard whereas the worst (A1) is some 38% (or approximately 2.6 times the resistance of present day "high conductivity" copper).

Finally, it is interesting to observe that of all the ten specimens, those which appear to be the poorest in terms of conductivity are contained within the three samples from apparatus used by Faraday in his researches on electro-magnetic induction. Thus, specimen A1 has a specific resistance in the order of .4 Ohms per gram metre and this

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- 1 Professor King states:- "There is no positive evidence that this is the original suspending wire. It might have been used in the repair of the balance at any time. However, there is no specific indication that it is not original". Private communication 9th February 1978.
- 2 It is interesting that in only one case (A1) has Arsenic been found as the predominant impurity and the element principally responsible for increased specific resistance.

poor result, along with similar performances in the other specimens, has an interesting significance. It may be supposed that had all things been against Faraday (i.e. a lower battery power and an insensitive galvanometer) and had he to contend with high resistance wire, then his great discoveries might well have been delayed. The slight deflection in the galvanometer, first observed by Faraday during his experiments on electro-magnetic induction in August 1831,¹ was a result of favourable circumstances. Had Faraday been able to predict, before his experimental results, the conditions in his circuits necessary to provide a near ideal result, then no doubt he would have done so. Interestingly, one of the main areas where precedence existed for comparing the efficacy of his circuit elements lay in the area of metallic conductors. A. C. Becquerel's work (vide infra Ch. 5 p. 68) in 1826 had revealed the comparative conductivities of metals and the fact that it was possible to be selective over the quality of copper, and thus the conductivity of copper wire. That Faraday appears not to have undertaken any selection procedure regarding his conductors (confirmed by the variability of the samples) is indicative of two possible attitudes. Firstly, that Faraday was aware of Becquerel's work but considered it of no consequence; or second, that he was not aware of it and so could not act upon it. In any event, there is no doubt that it might have been a costly omission, for his first positive result was only a "very slight deflection at the galvanometer"² and this, with an arrangement of two coils of copper wire 203ft long and wound around wood.³ It must however, be borne in mind, that Faraday was conducting a series of planned experiments and any such failure, as imagined above would probably have cost days, rather than years, in Faraday's discovery of electro-magnetic induction. However, with Joseph Henry working independently on the same phenomena, Faraday might well have lost credit for his discovery.

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- 1 Faraday M. Notebook . Royal Institution.
- 2 Faraday M. "Experimental Researches" Part 1 Phil. Trans. V11 1832 p. 125, 127.
- 3 Ibid.

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The Rise of Copper Wire, Its
Manufacture and Use to 1900 - A
Case of Industrial Circumspection.

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Thesis Illustrations - 1980

Barrie C. Blake-Coleman

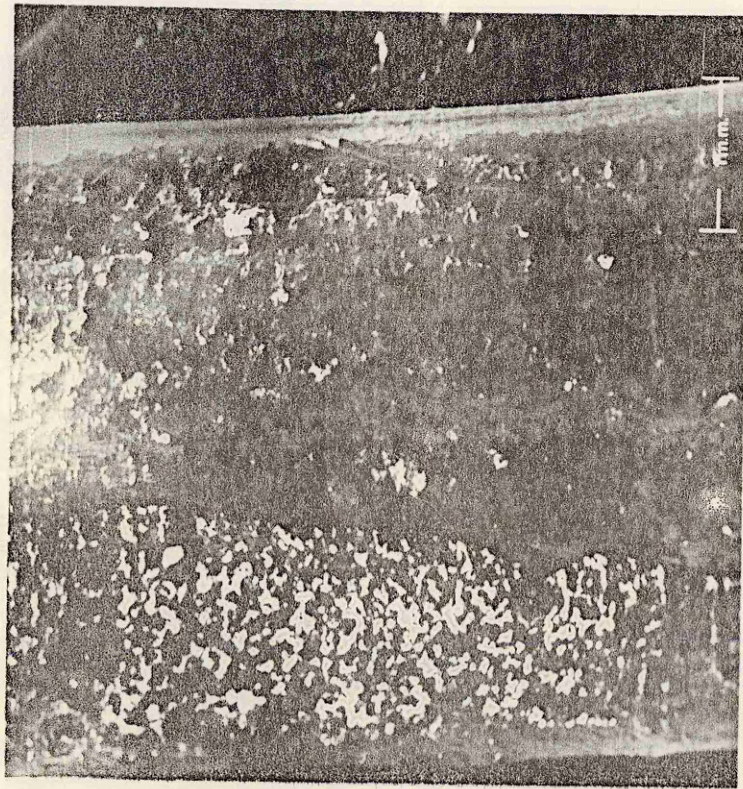


PLATE 1a



PLATE 1b

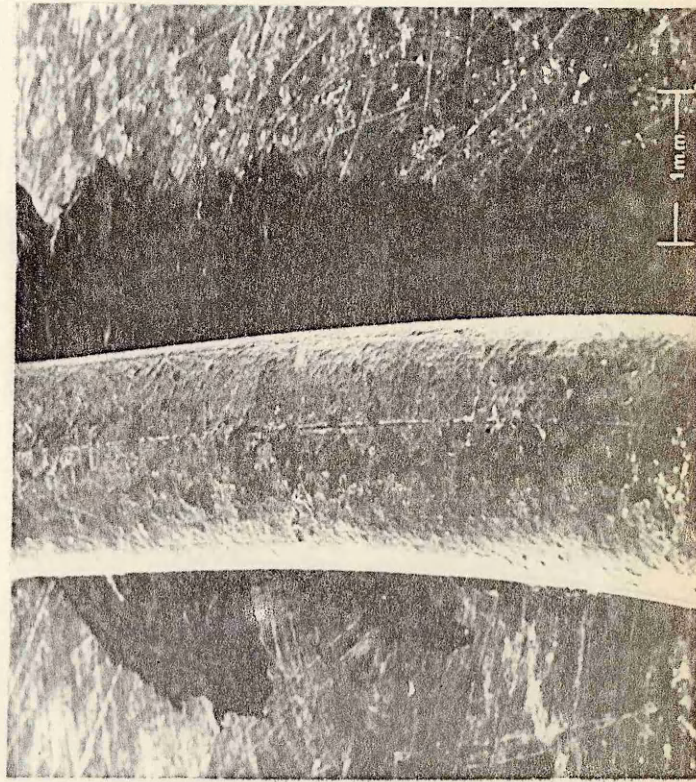


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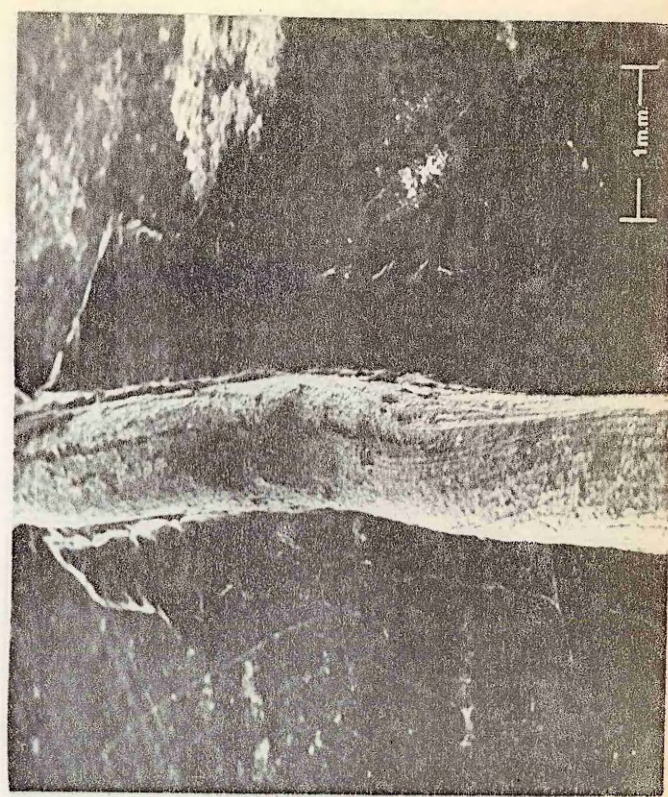


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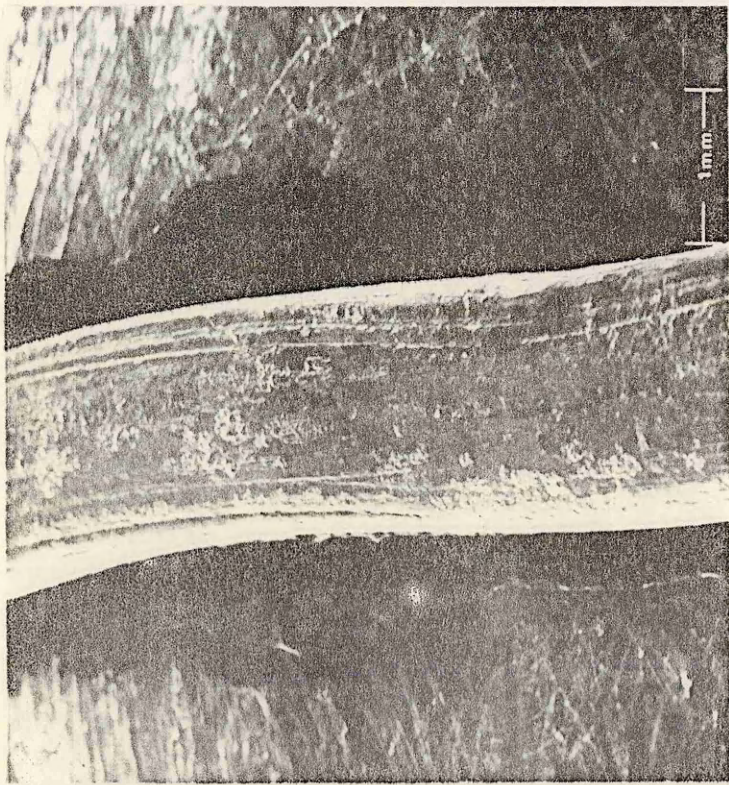


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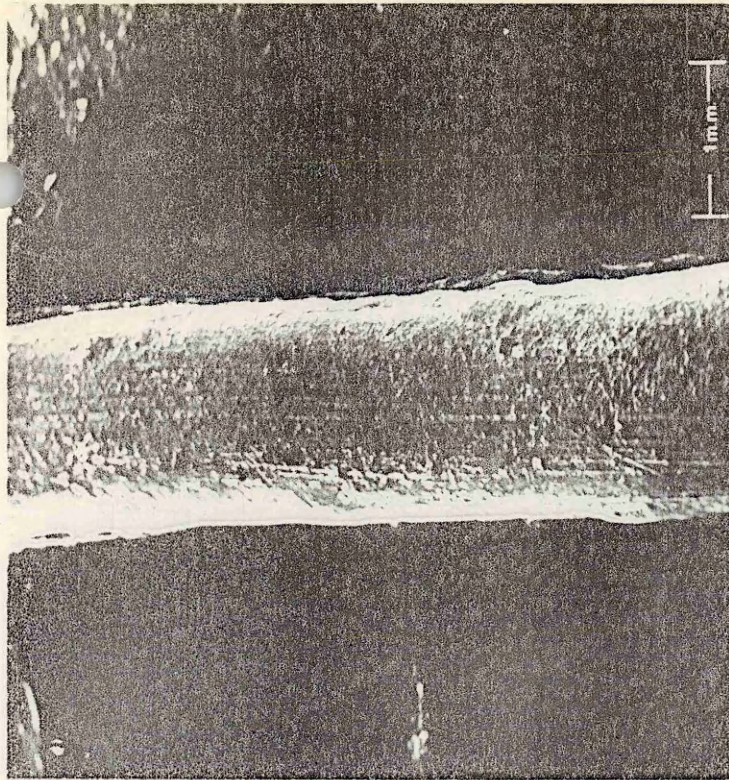


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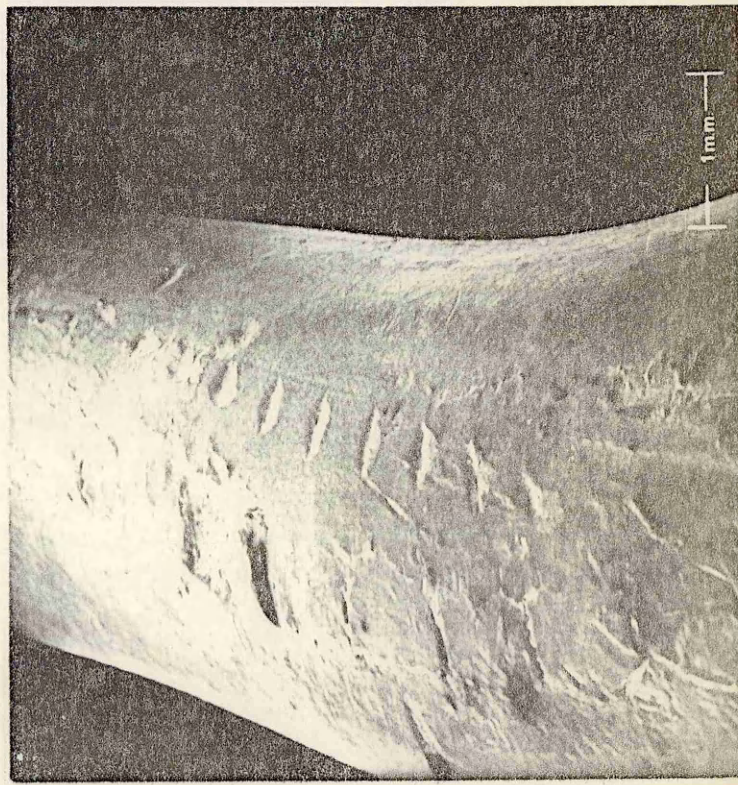


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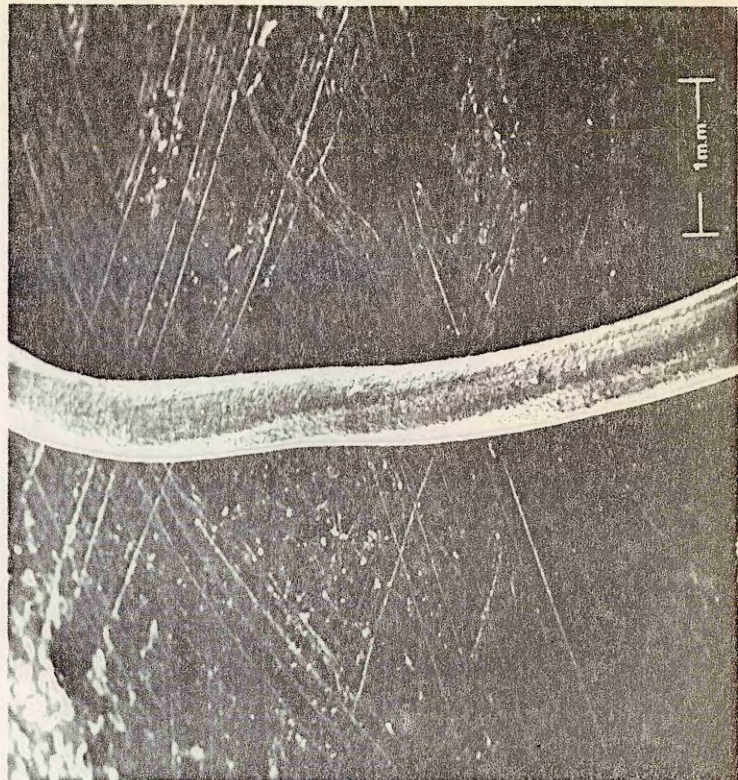


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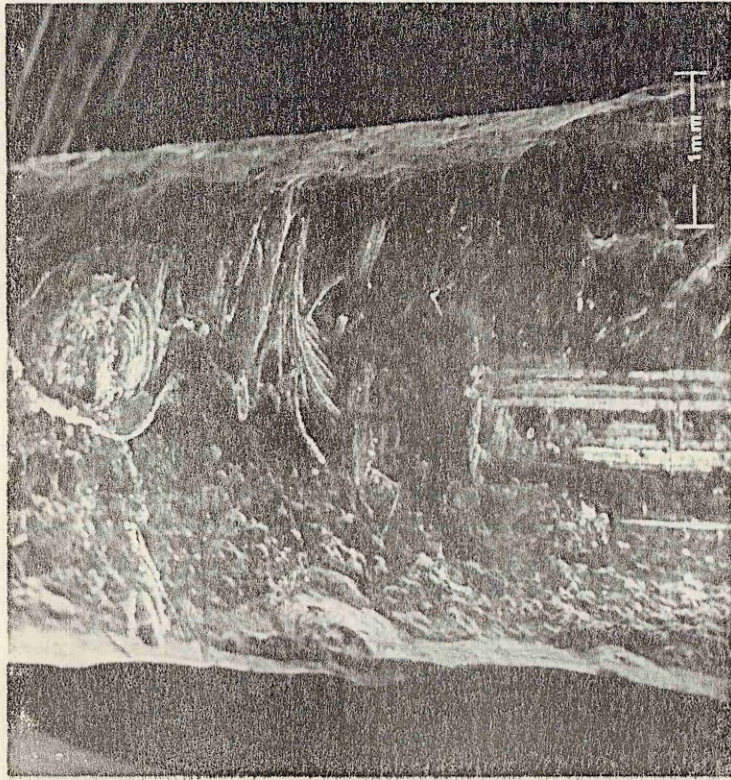


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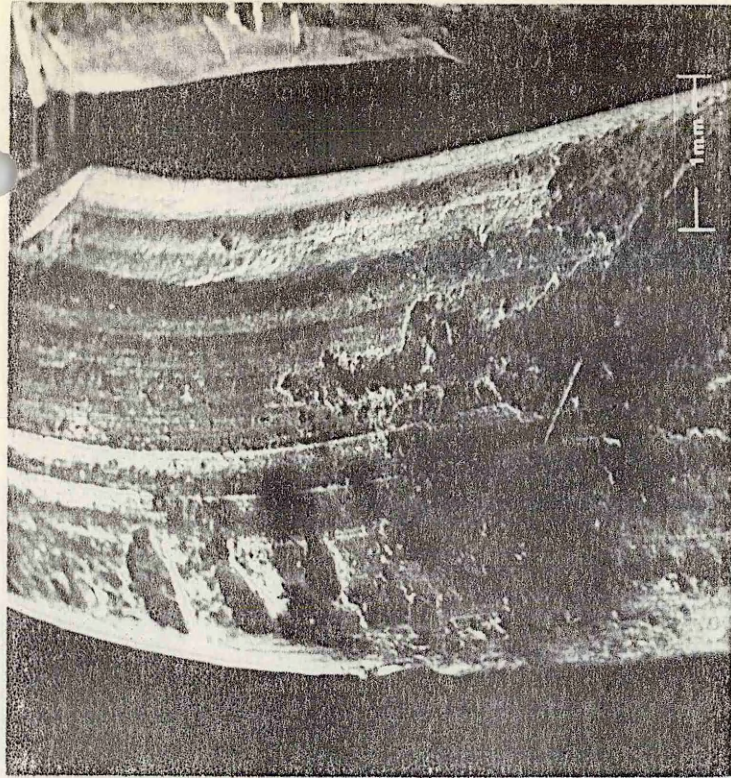


PLATE 9



PLATE 10



PLATE 11

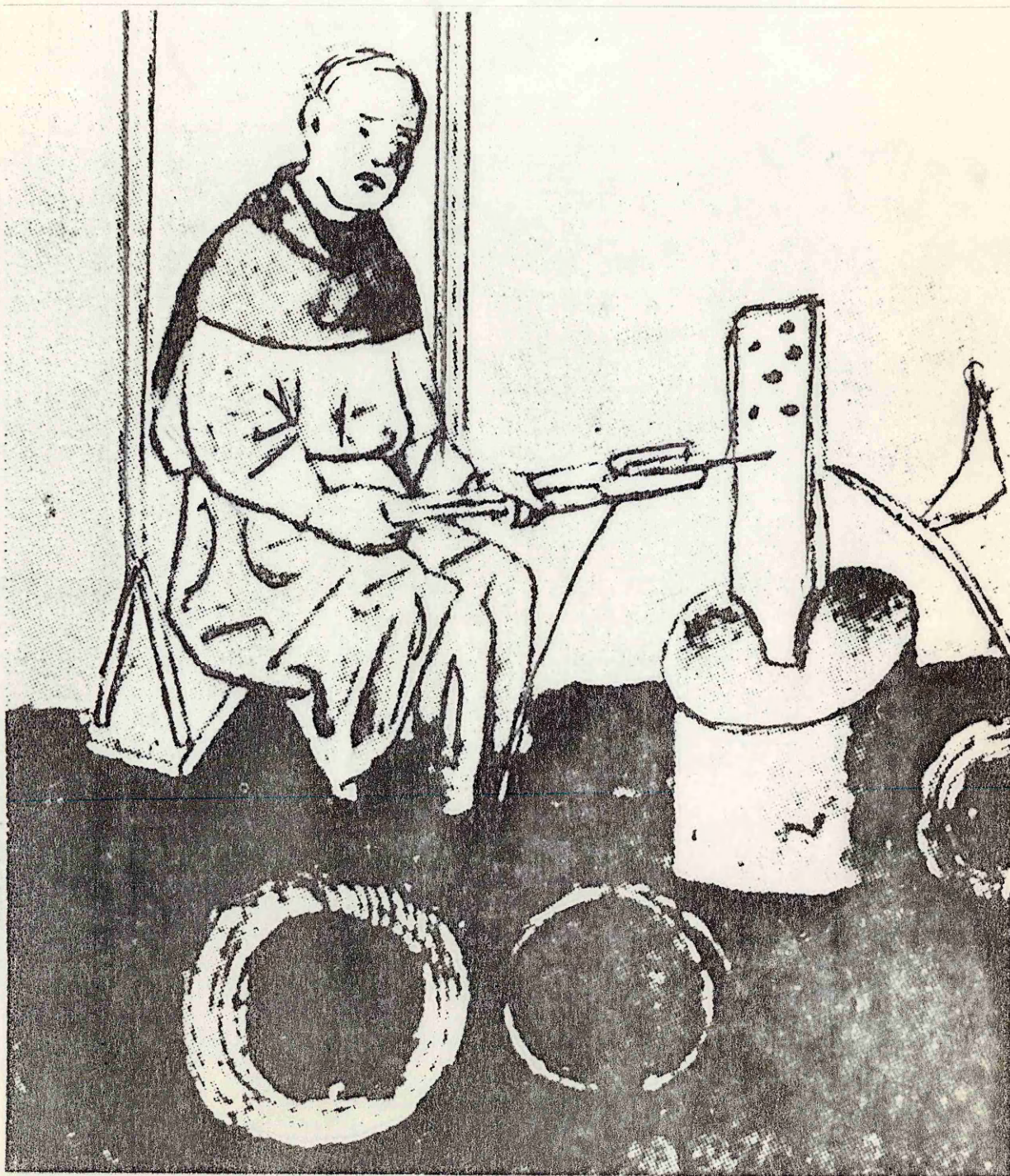


PLATE 12

PLATE 1 - 10

Faraday samples - see Appendix 2

PLATE 11

Wire drawing circa 1389 - from Lewis K. B. "Wire Beginnings" Wire Industry 3, 25, January 1936 p. 7.

PLATE 12

Wire drawer and swing seat, circa 1418 - Ibid.

PLATE 13

Heavy wire drawing, water assisted with swing seat and grips - Biringuccio V. "Pyrotechnia" Venice 1535 Chapter 8 p. 141.

PLATE 14

Twin block of 1527 - Lewis K. B. "Primitive Processes of the Early Days" Wire Industry 3, 25, February 1936 p. 7.

PLATE 15

Early manual tilt hammer for battery - Bessoni J. "Il Theatro de Gl'instrumenti e Machine" Lyons 1582.

PLATE 16

Water powered trip hammer - Bockler G. A. "Theatrum Machinarum Novum" Nurnburg 1661.

PLATE 17

Water powered trip hammers circa 1763 - Diderot D. "Encyclopédie" - (Recuell de Planches, sur Les Sciences, Les Arts Liberaux, et Les Arts Mechaniques. Paris 1763) reprinted in "A Diderot Pictorial Encyclopaedia of Trades and Industry" Dover, New York 1959.

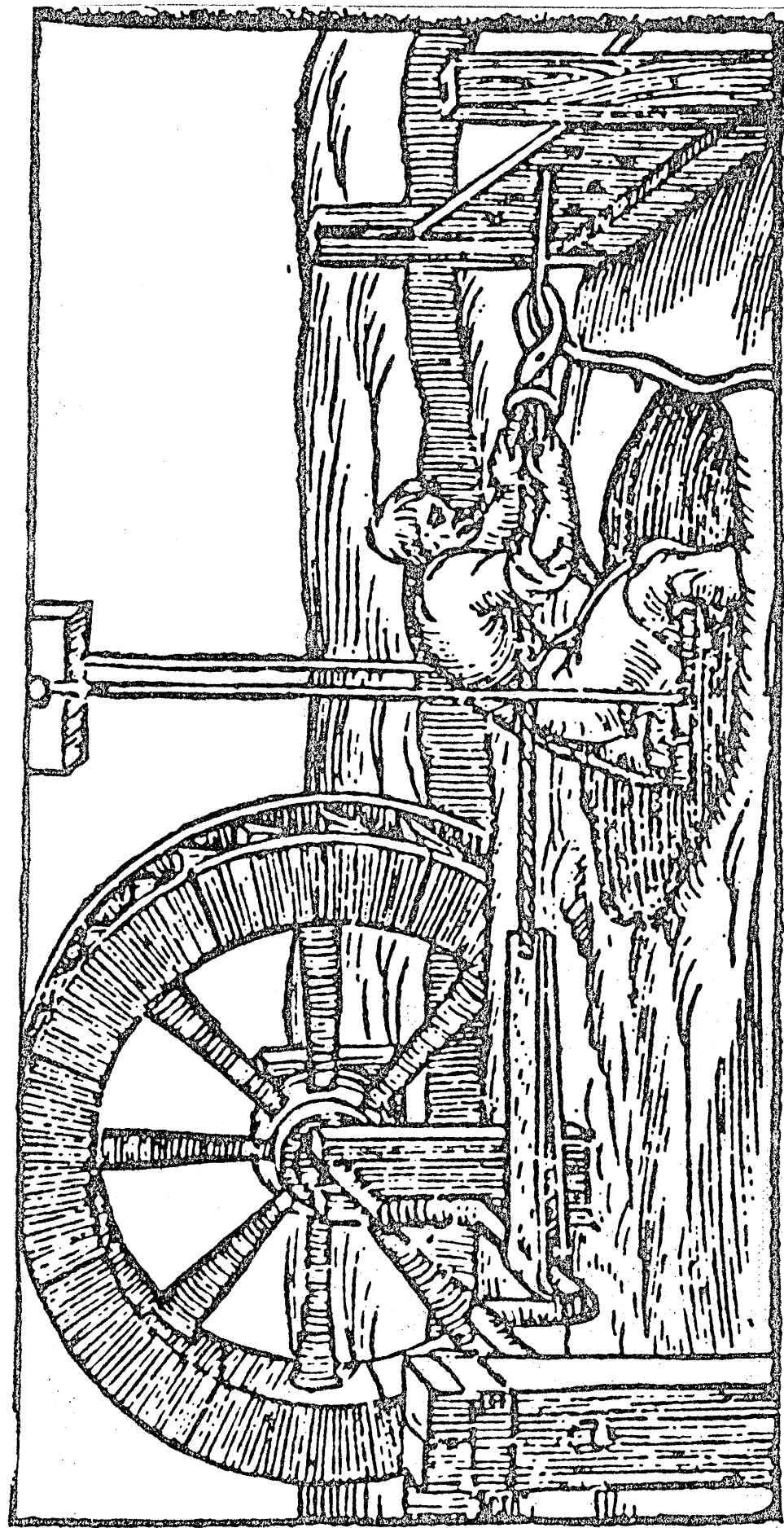


PLATE 13



PLATE 14

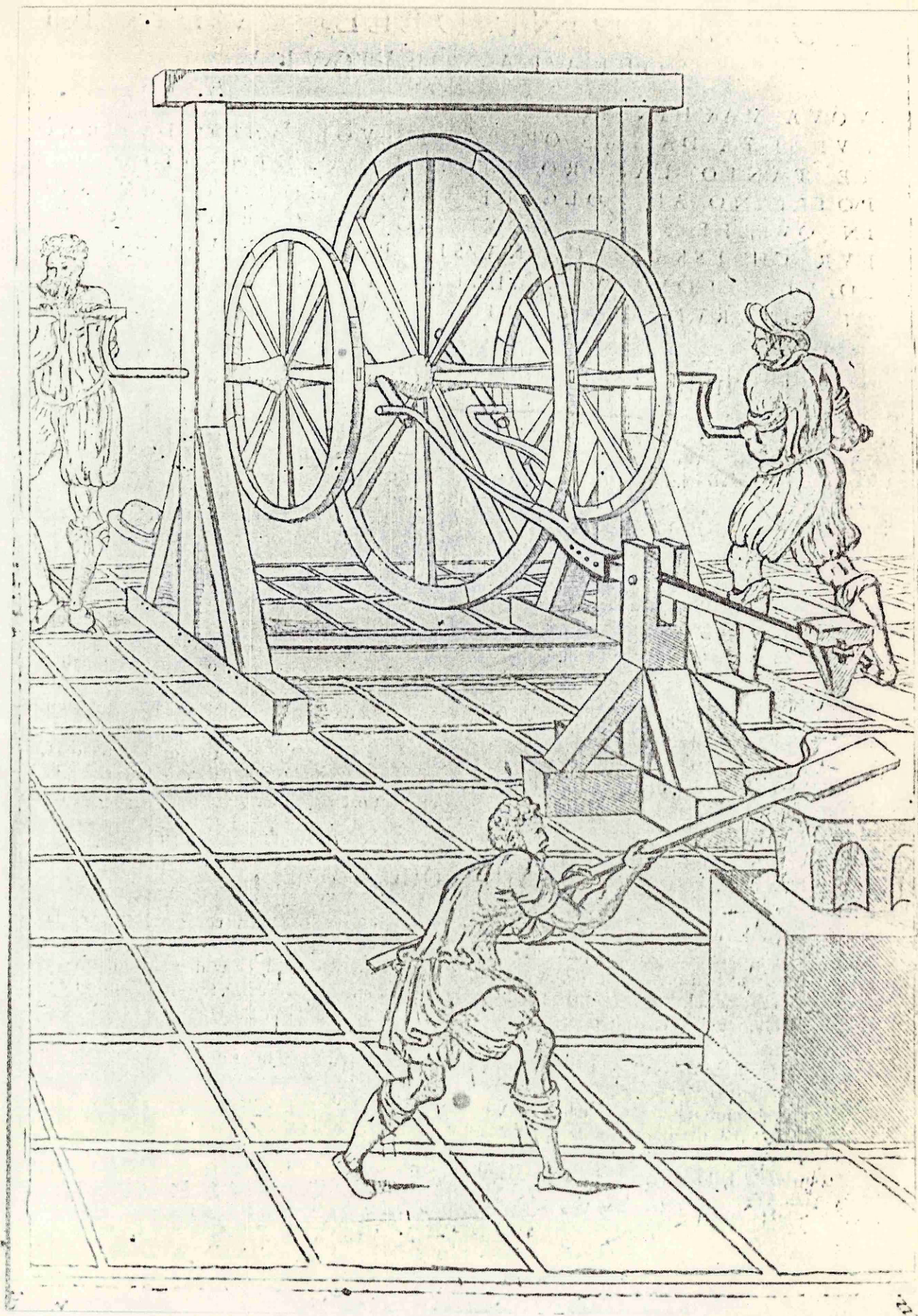
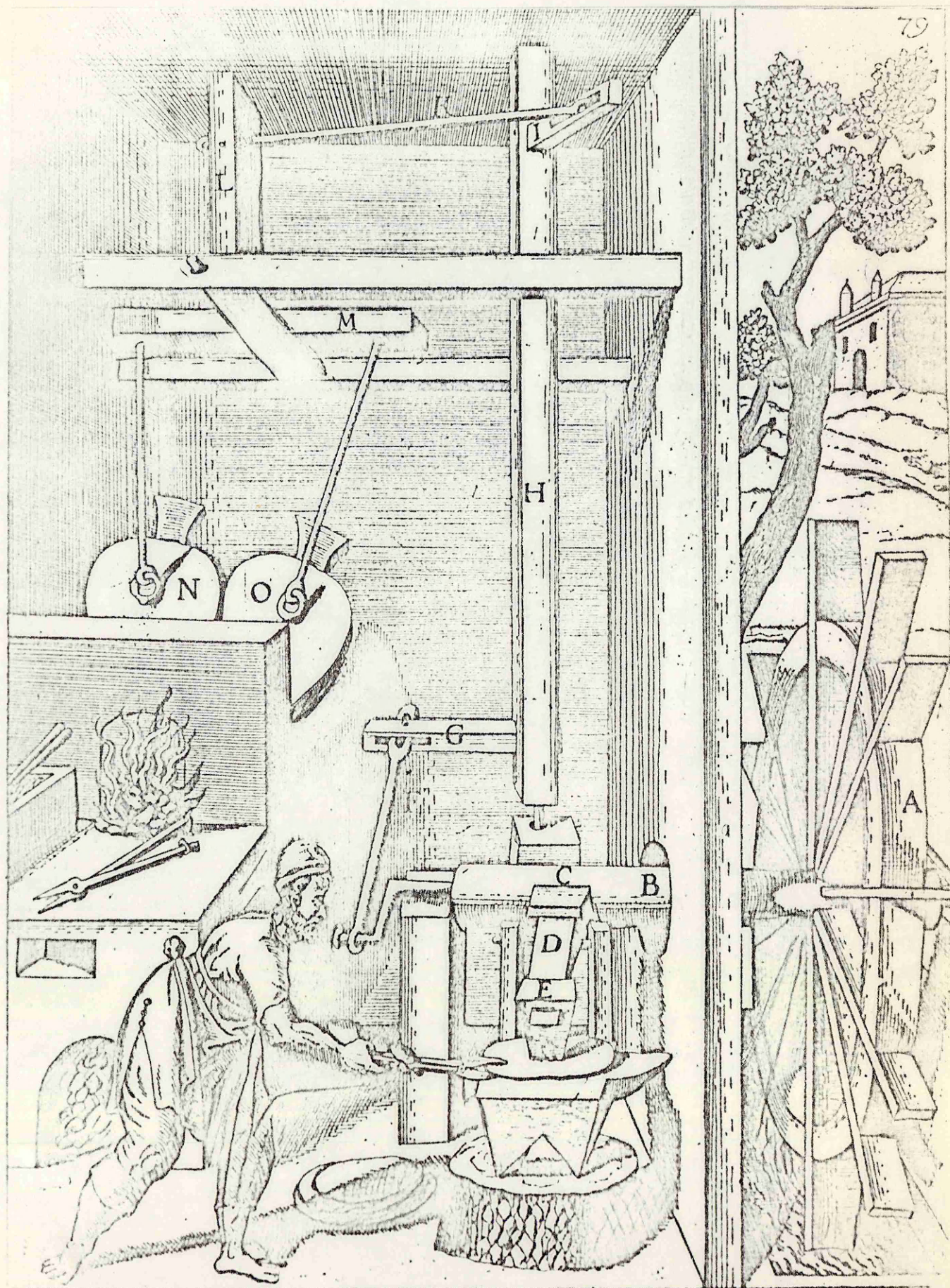
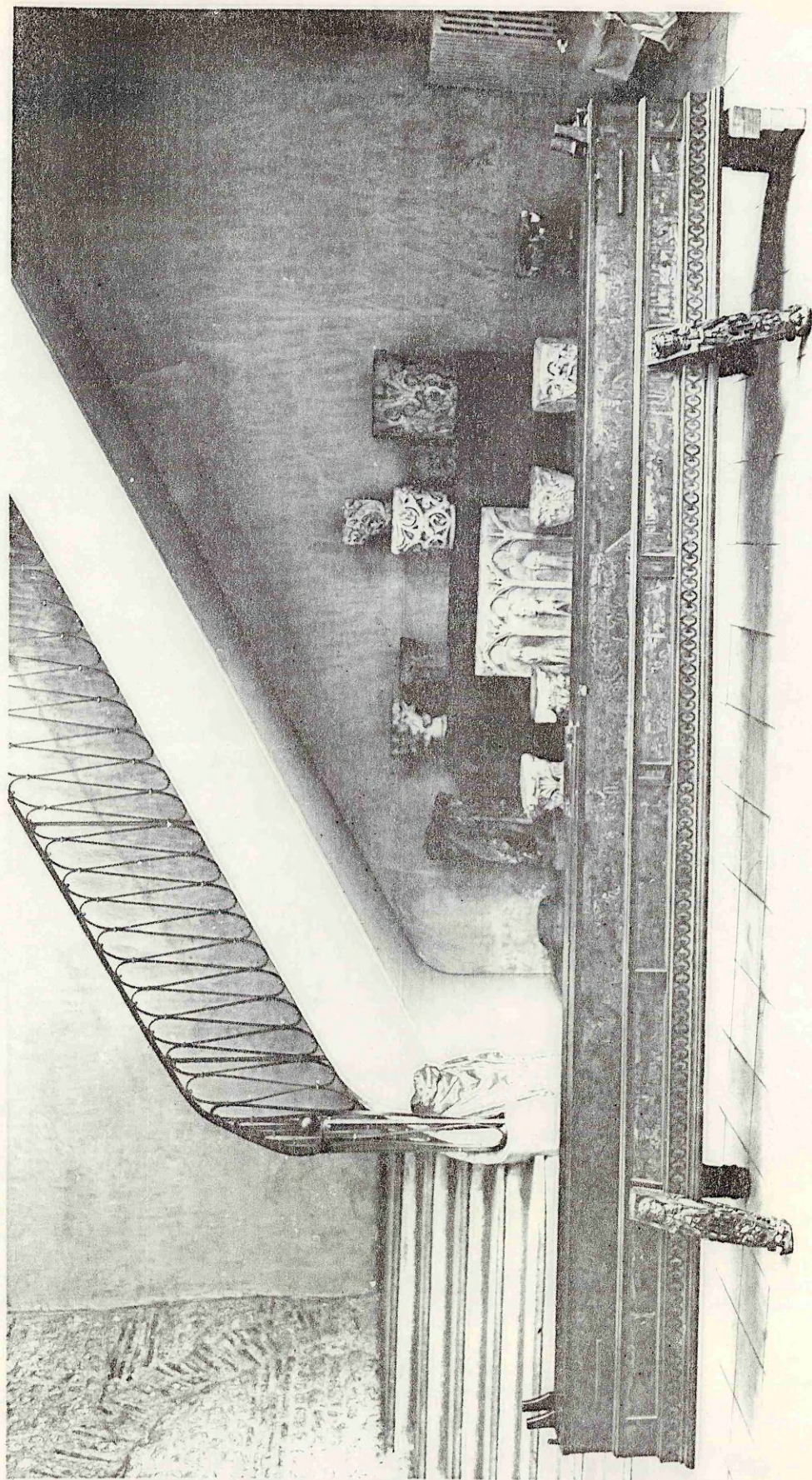


PLATE 15





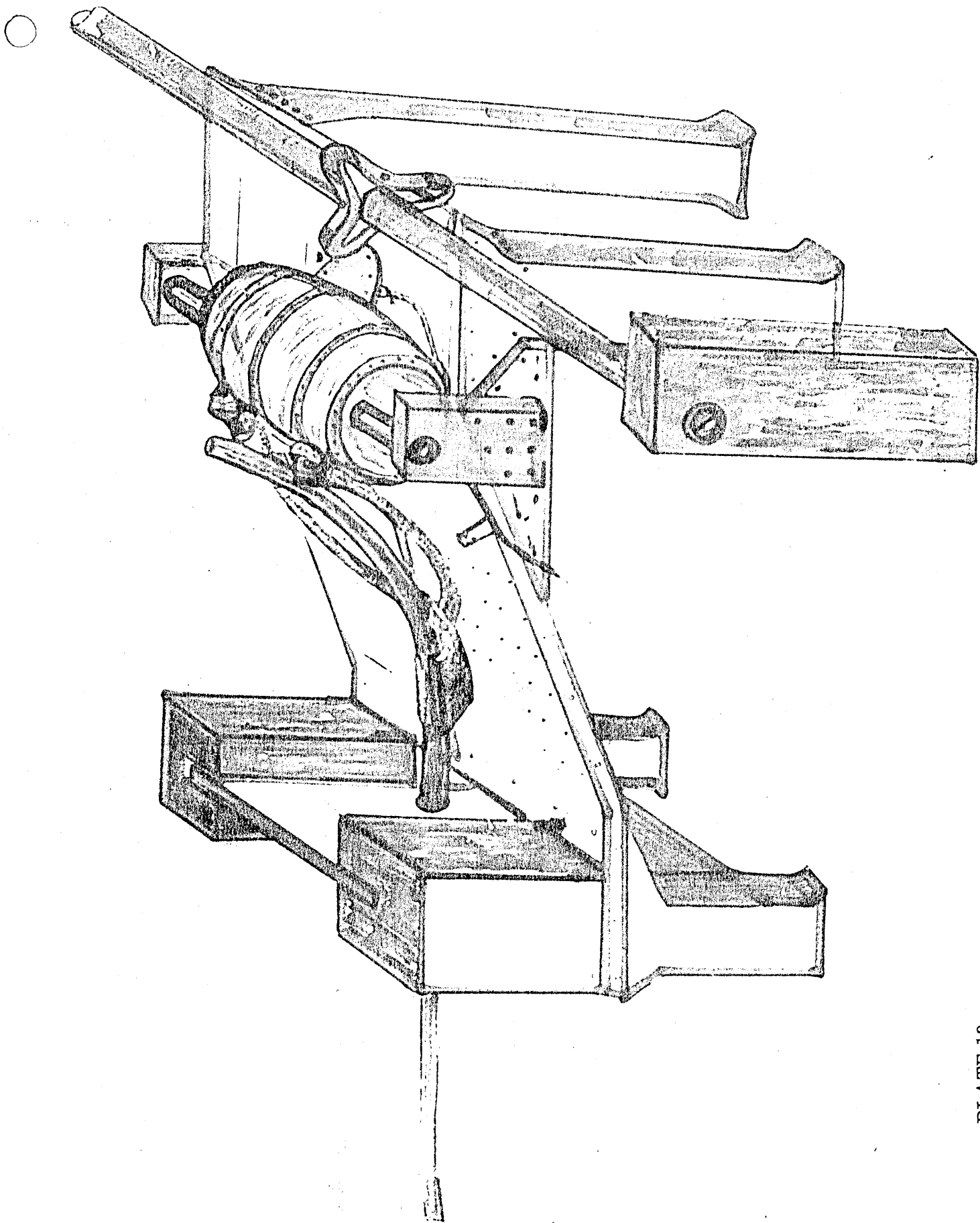
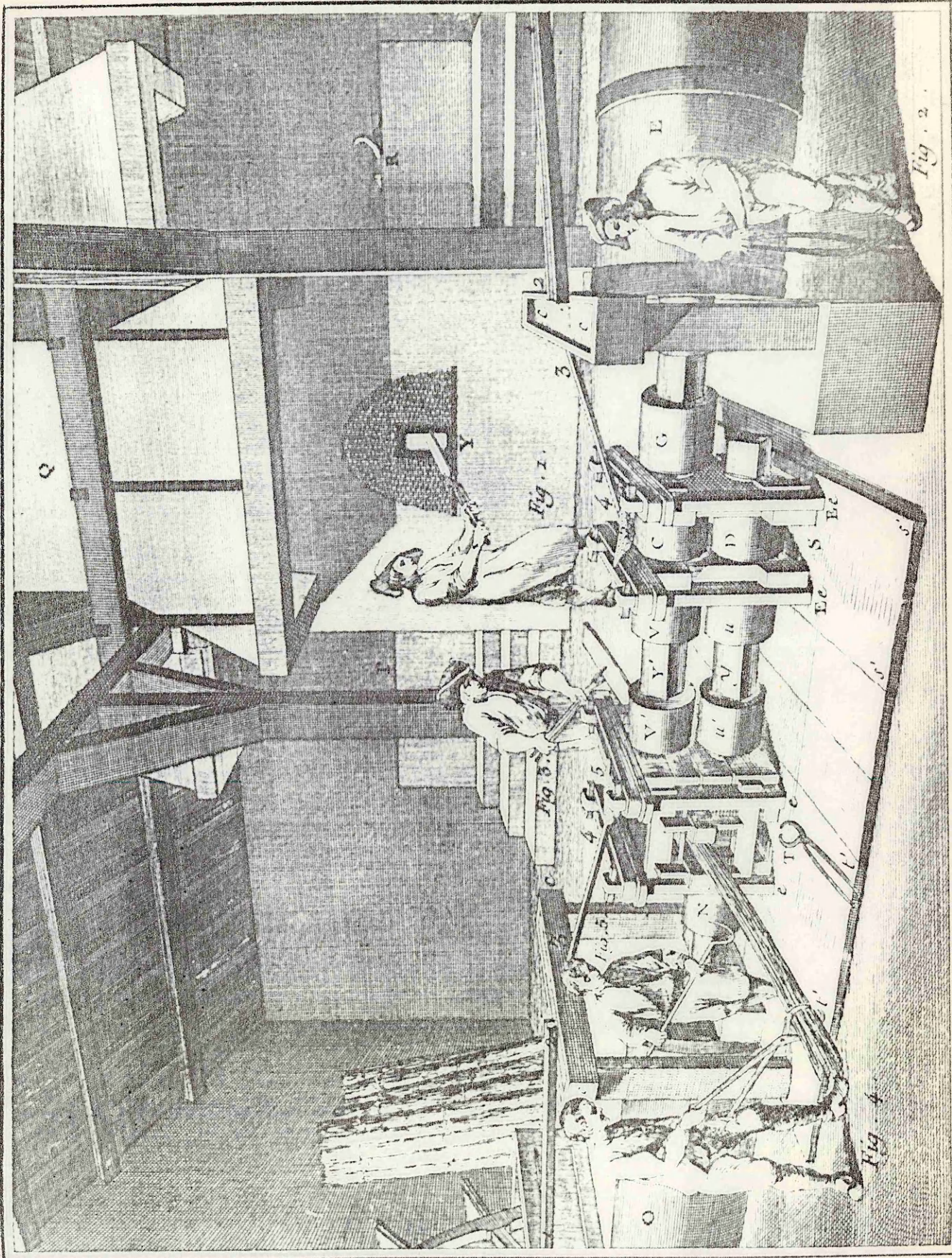


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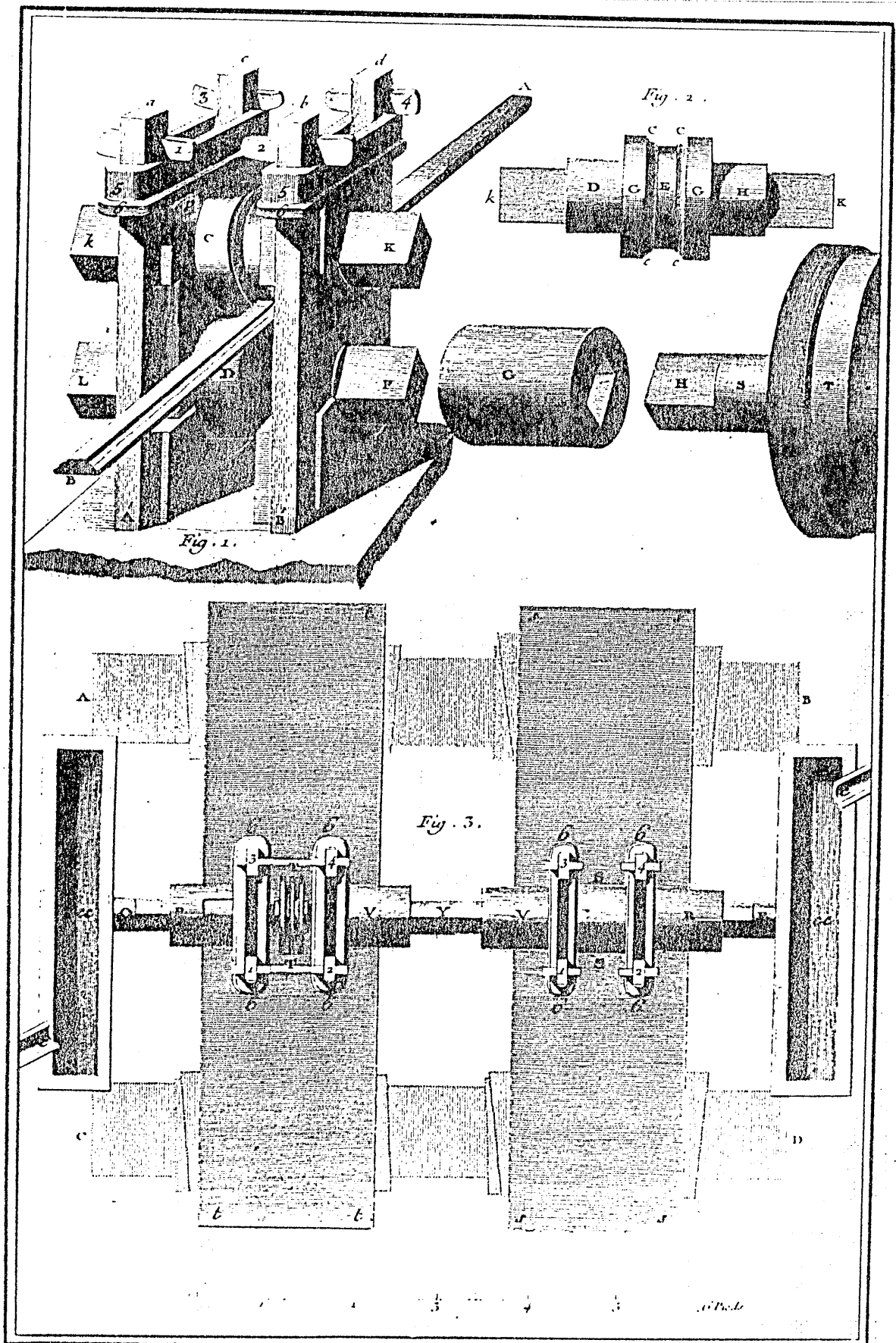


PLATE 18

Wire-drawing "cric" of Leonhard Daner. Photo - Musee de Cluny a Paris.

PLATE 19

Reconstruction of Tintern "Ripping" wire-drawing machine as described by Ray.
See text.

PLATE 20

Rolling and slitting mill circa 1763 from Diderot op cit. (Plate 99).

PLATE 21

Schematic of rolling and slitting gear. From Diderot op cit. (Plate 100).

PLATE 22

Self-acting wire-drawing machine. From Holland's "Manufactures in Metal" found in Lardner's "Cabinet of Useful Arts" Vol. 2 Chapter 14 p. 332. London 1839.

PLATE 23

Capstan, windlass and manually operated self-acting wire-drawing machines. From H. L. Duhamel de Monceau "Art de Metiers - Art de Redoire le Fer en Fil" Paris 1764 (B.M.1811.c.18(5)).

PLATE 24

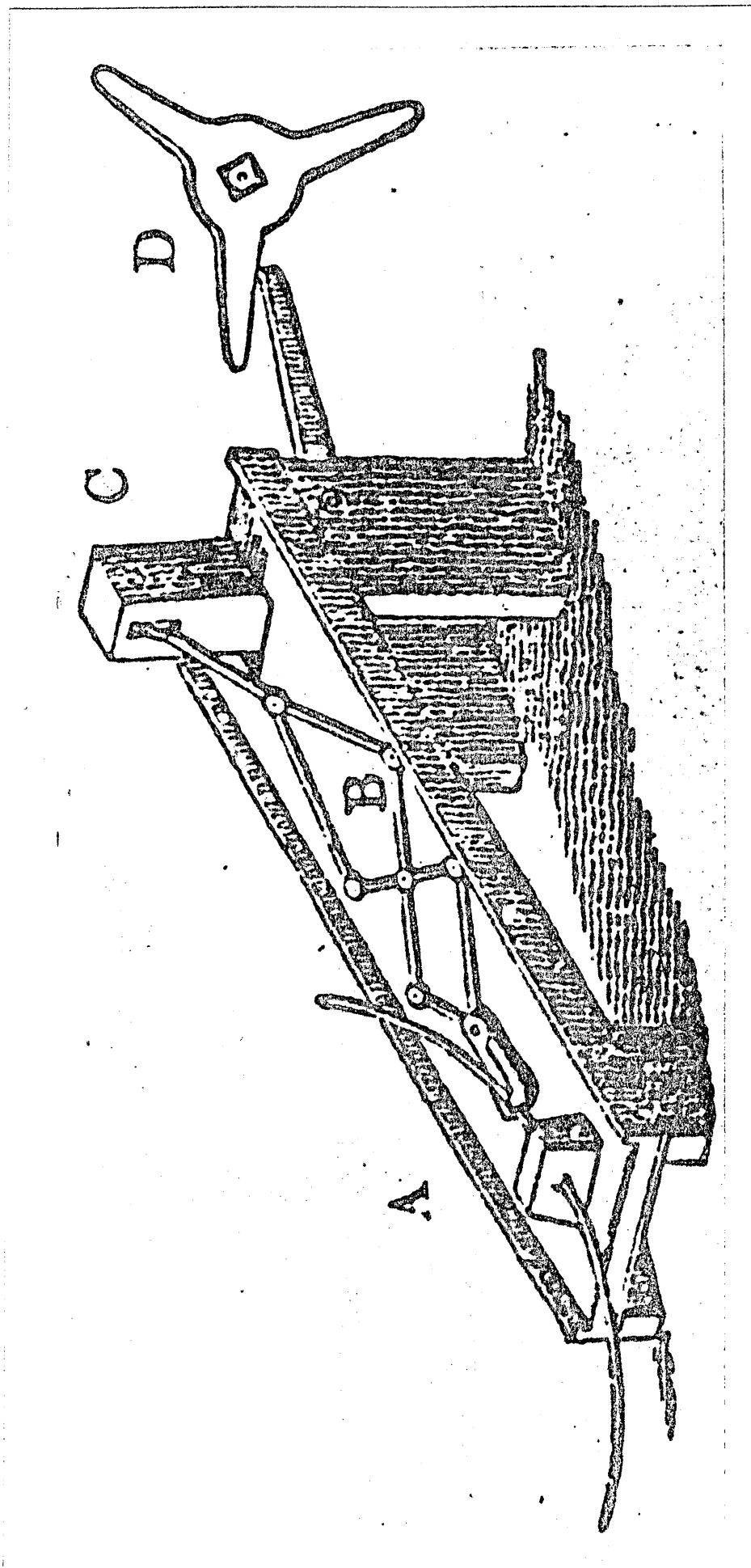
Schematic of self-acting wire-drawing machine. From Diderot op cit. (Plate 146).

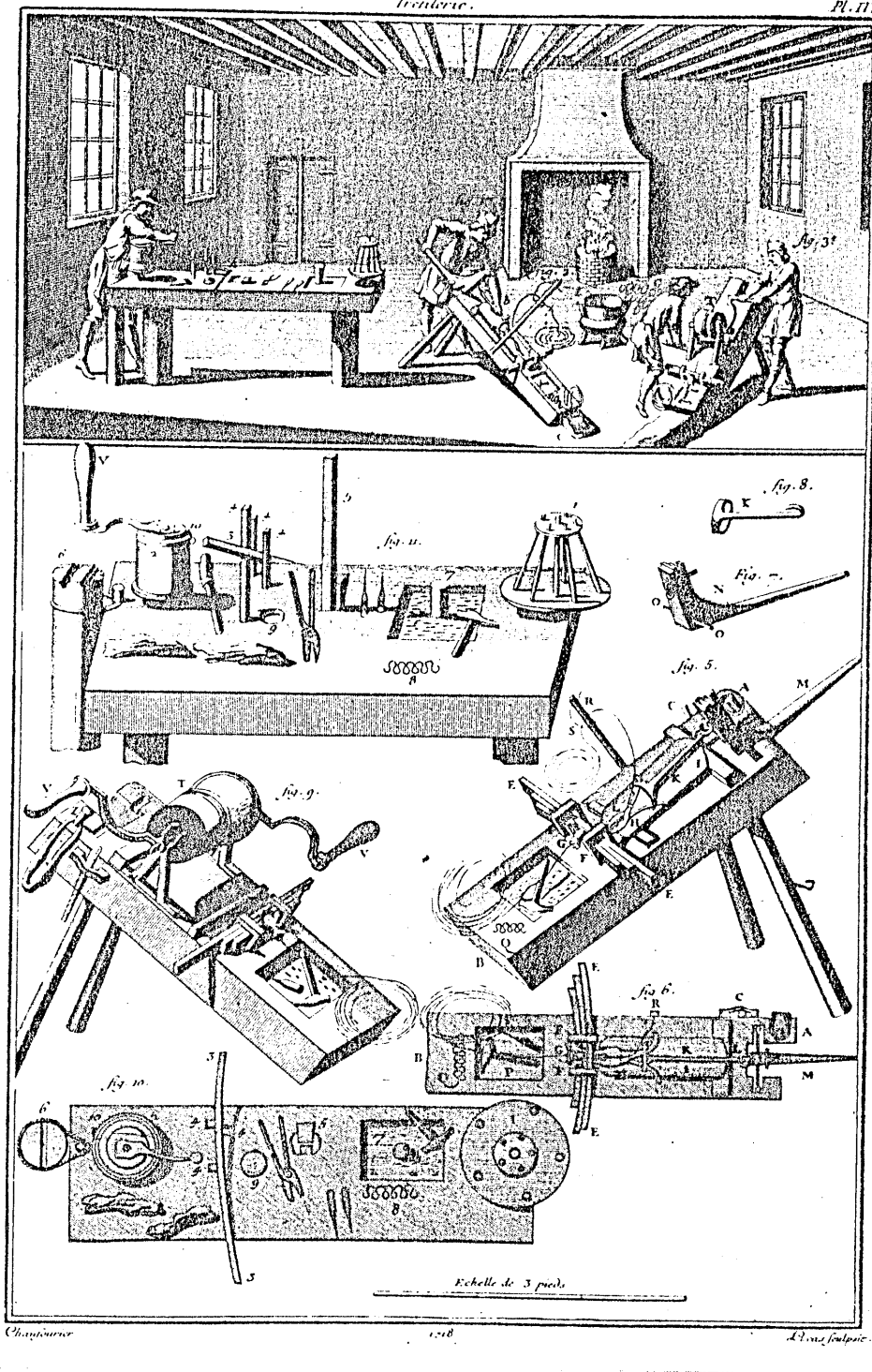
PLATE 25

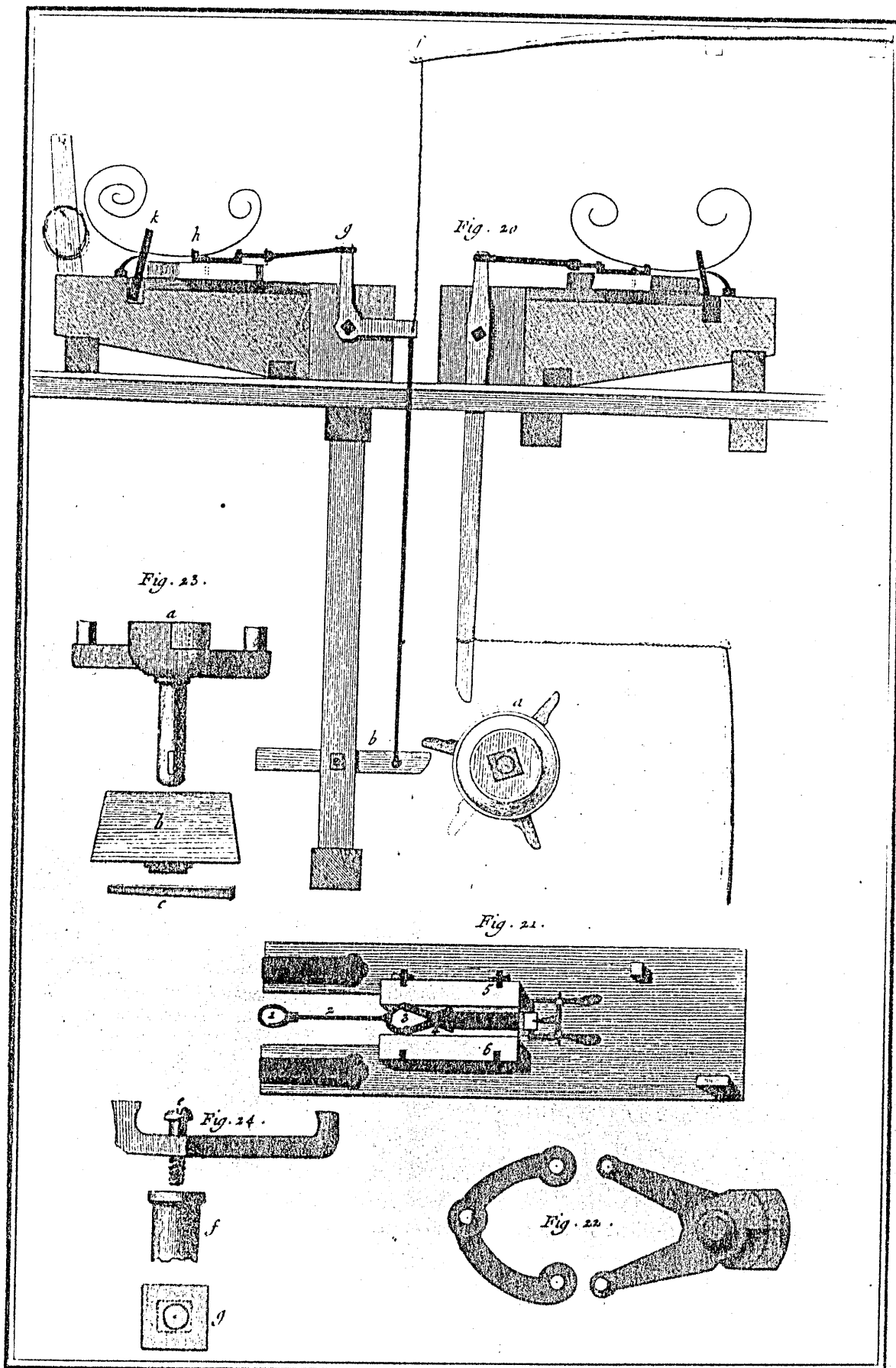
Self-acting wire-drawing machines in operation. From H. L. Duhamel op cit.

PLATE 26

Self-acting wire-drawing machines. From Diderot op cit. (Plate 145).







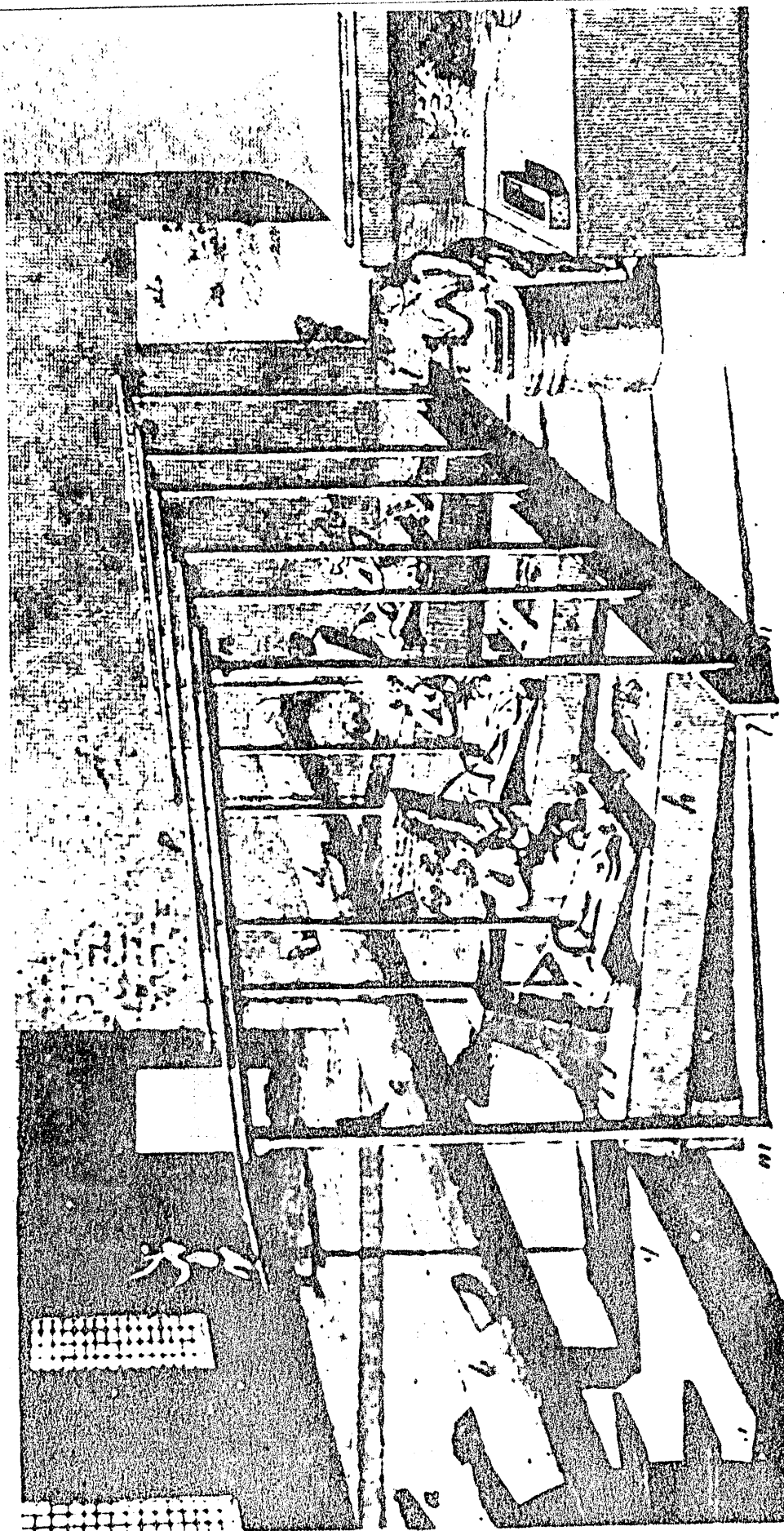
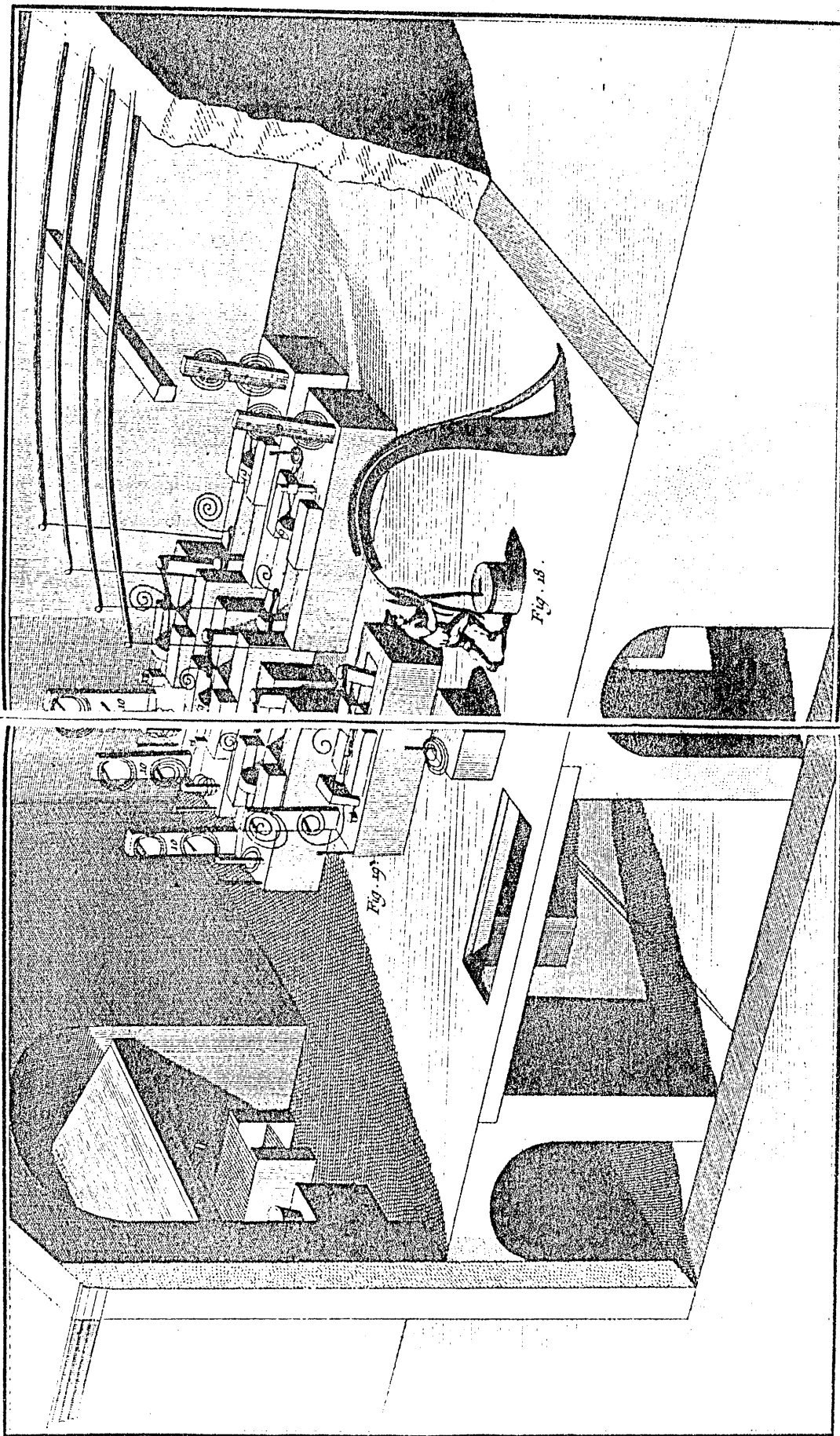
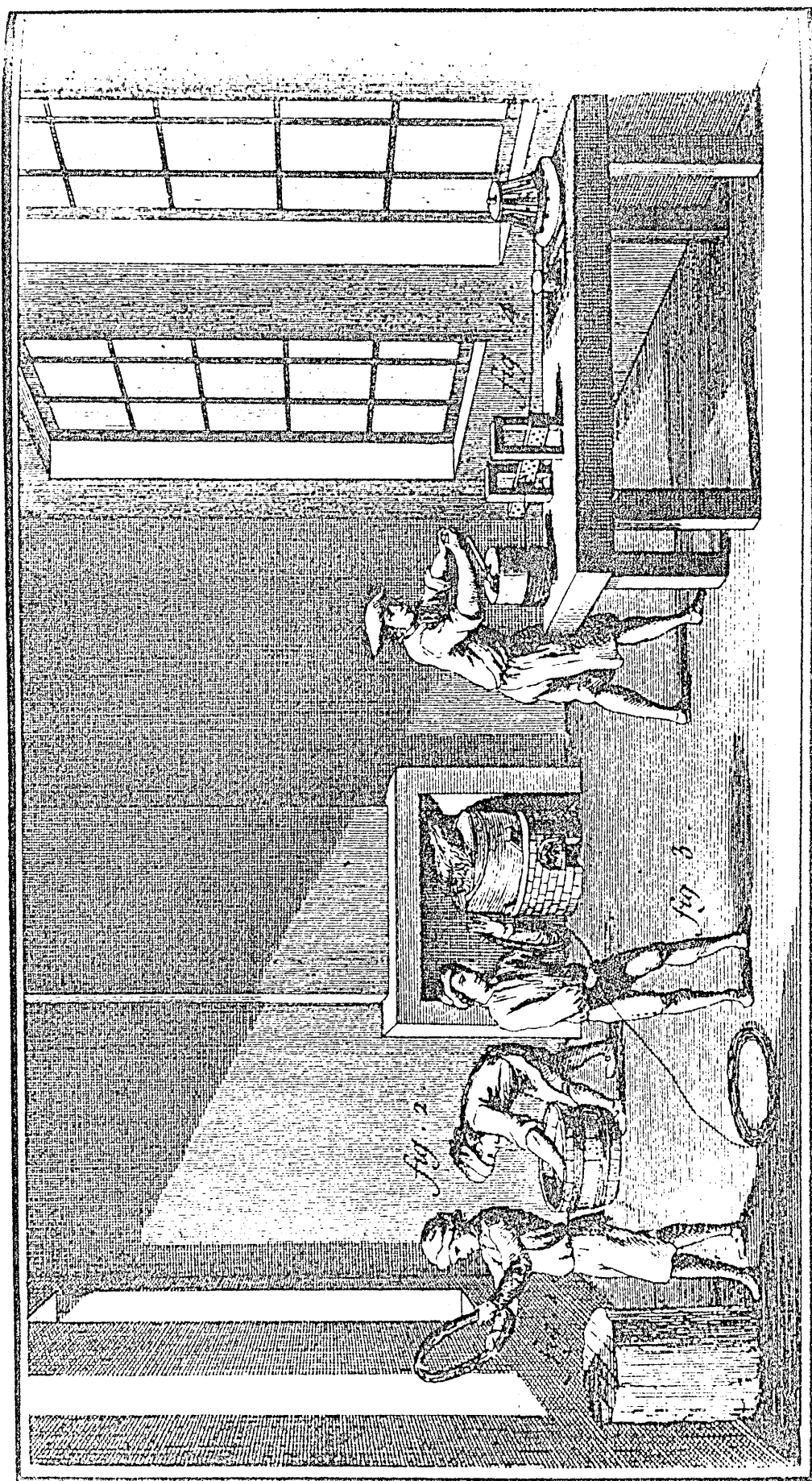
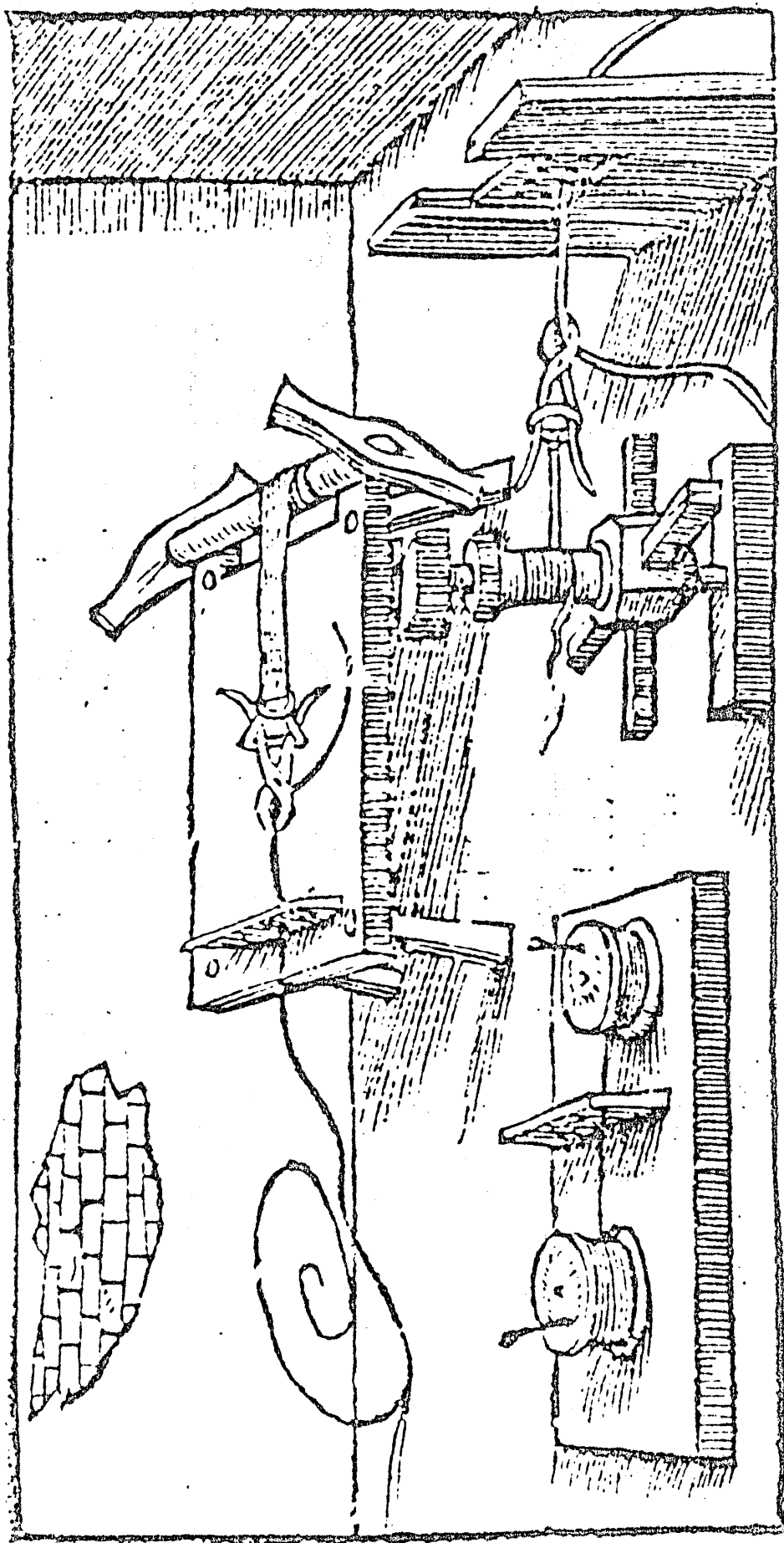


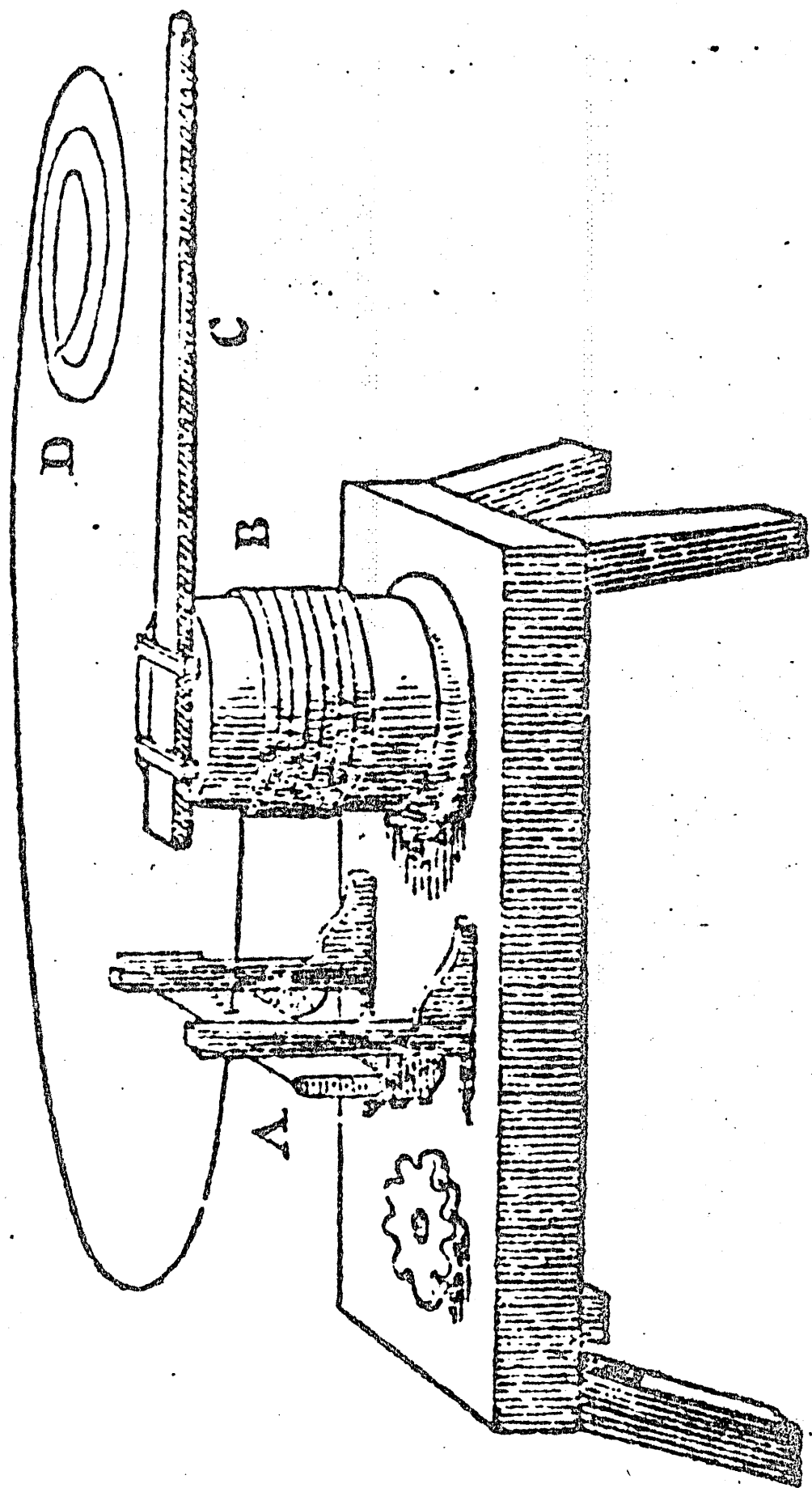
PLATE 25



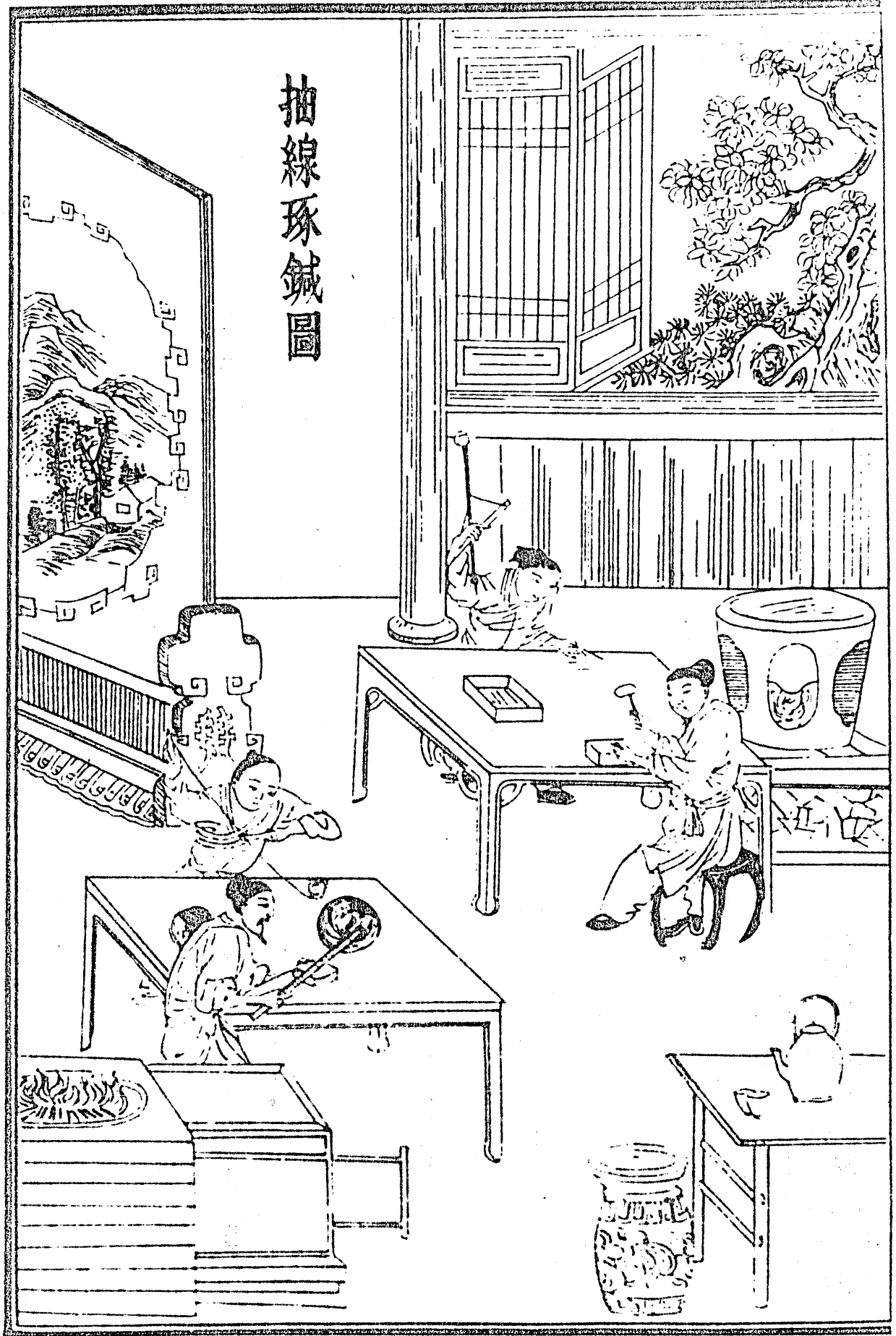
Vol. 17, Metallurgie, Calamine, Pl. 1.

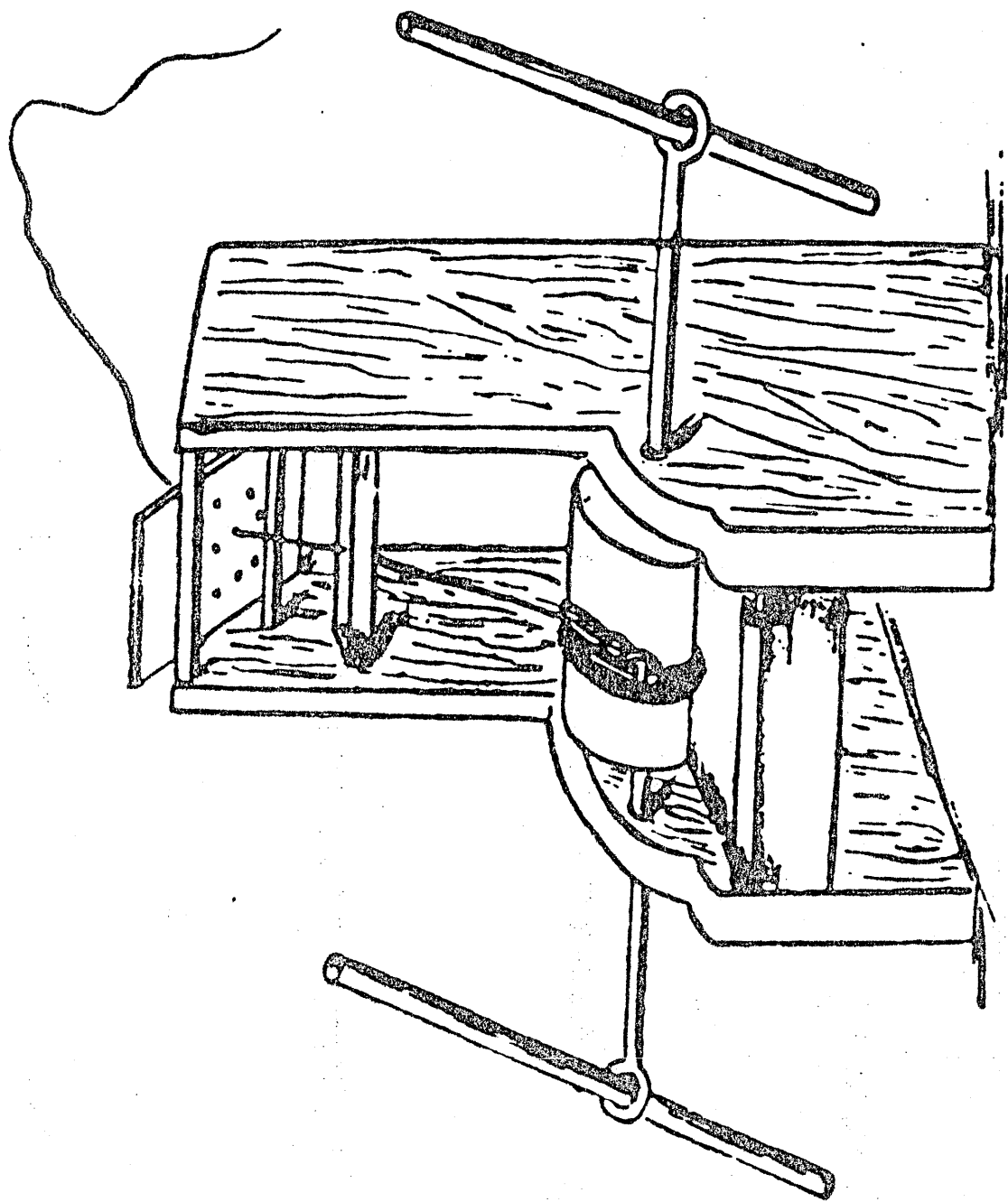






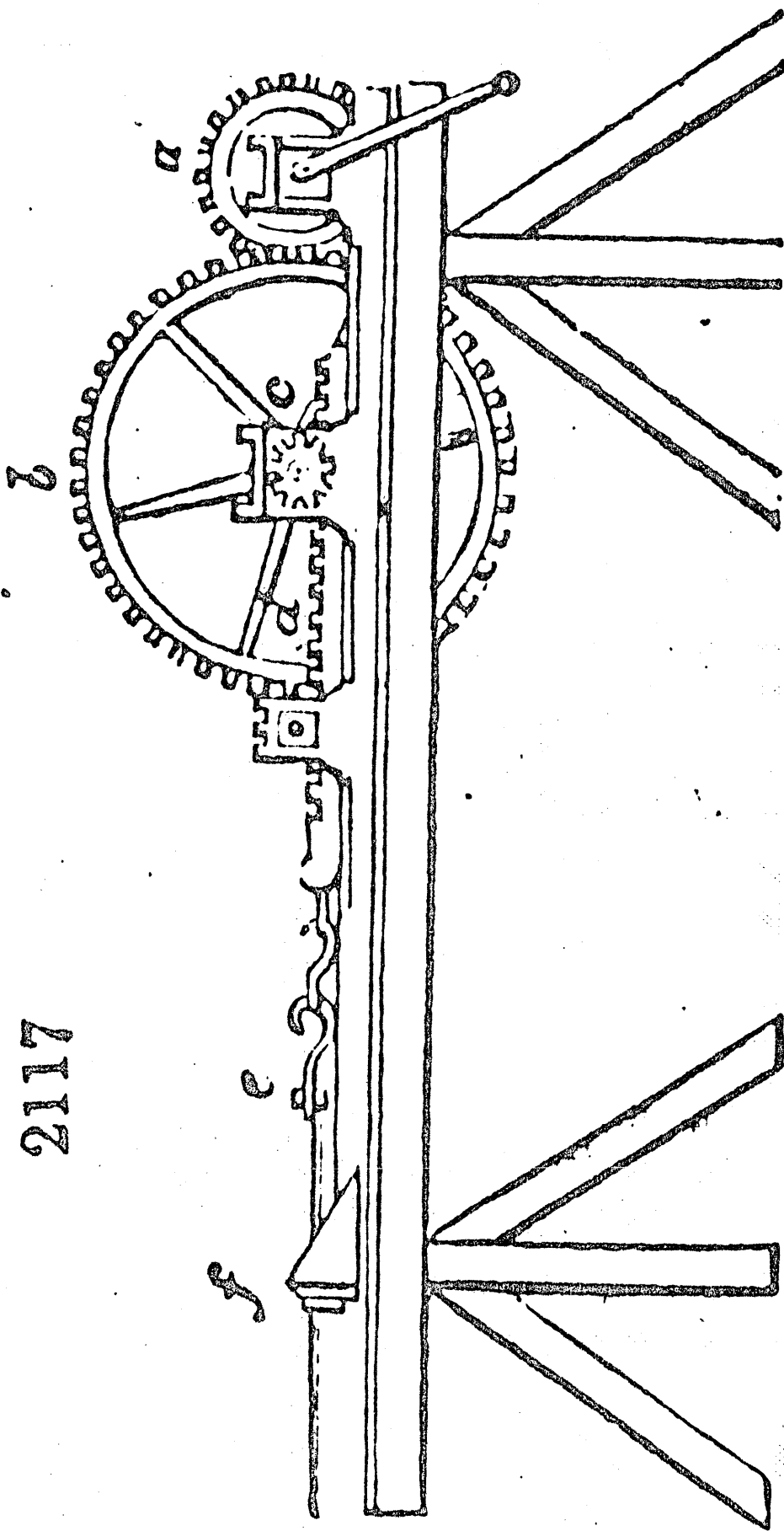
抽線琢鍼圖





援鉄線

2117



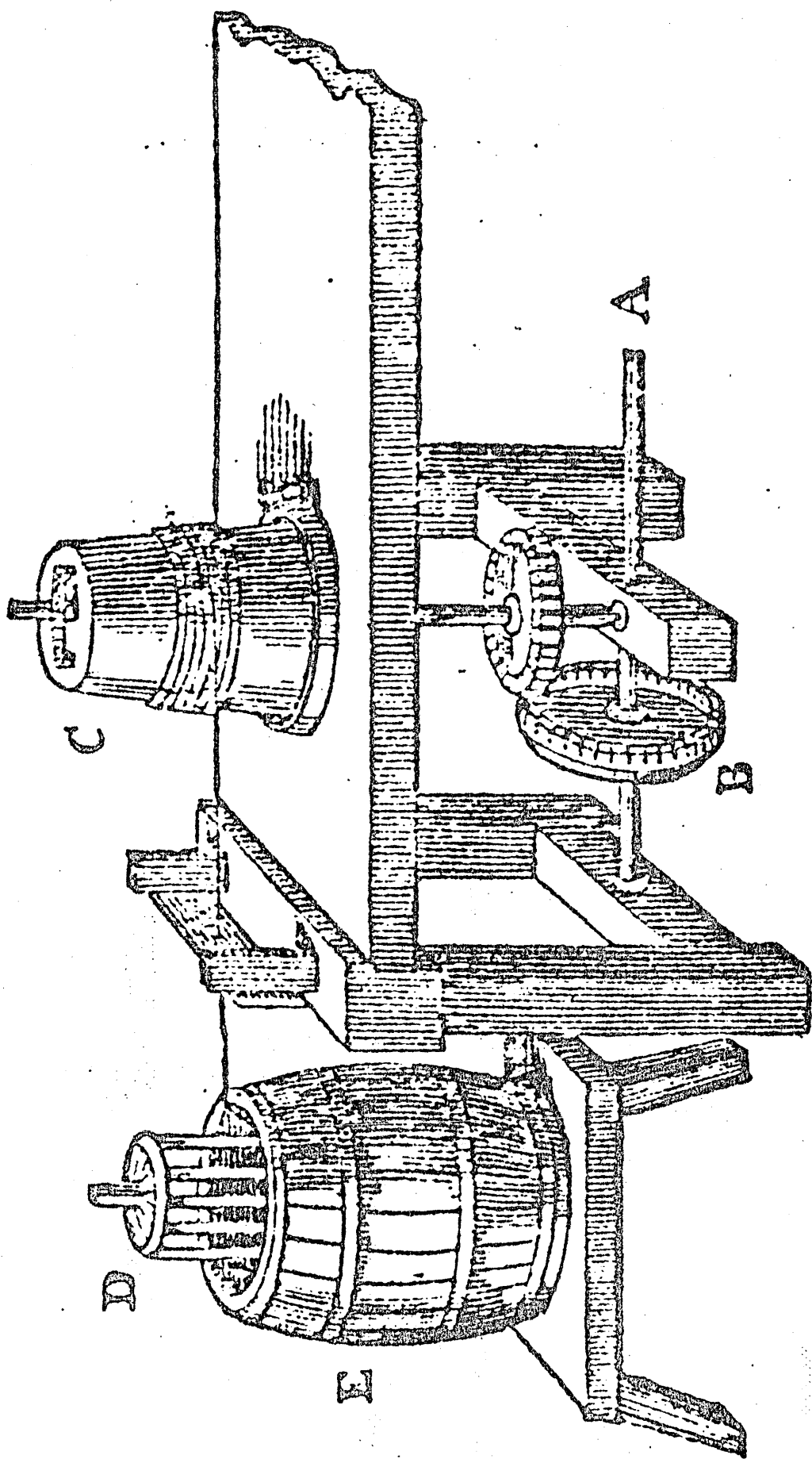


PLATE 27

Capstan wire-drawing bench (1763). From Diderot op cit. (Plate 184).

PLATE 28

Capstan and Windlass wire-drawing machines (1535). From Biringuccio op cit p. 140.

PLATE 29

Capstan wire-drawing bench (1838). From Holland op cit p. 336.

PLATE 30

Hand-drawing of wire (after Thien Kung Khai Wu circa 1637) from Needham J. "Science and Civilisation in China" Vol. 4 Part 1, p. 283. Cambridge 1962.

PLATE 31

Early Chinese windlass wire-drawing machine, after Needham J. - Ibid - Vol. 4 Part 2 p. 59.

PLATE 32

Late 19th century wire-drawing machine. From "Dr. Ures Dictionary of Arts" London 1878 p. 1151.

PLATE 33

Early 19th century wire-drawing bench utilising powered capstan - after Holland op cit p. 338.

PLATE 34

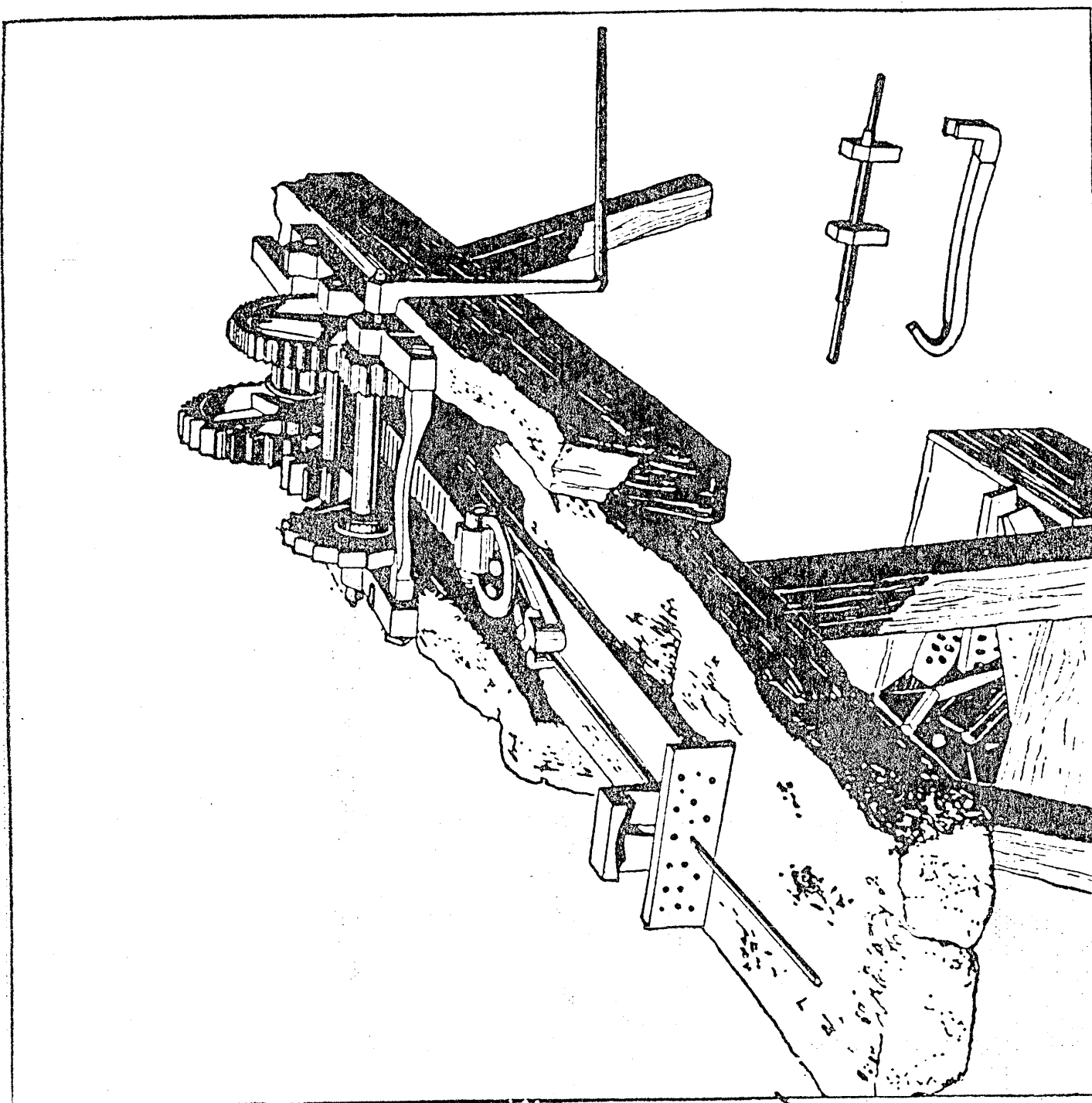
Bradbury F. Article "Sheffield Plate". The Encyclopaedia Britannica Vol. 20 p. 481 - Chicago University Press 1957.

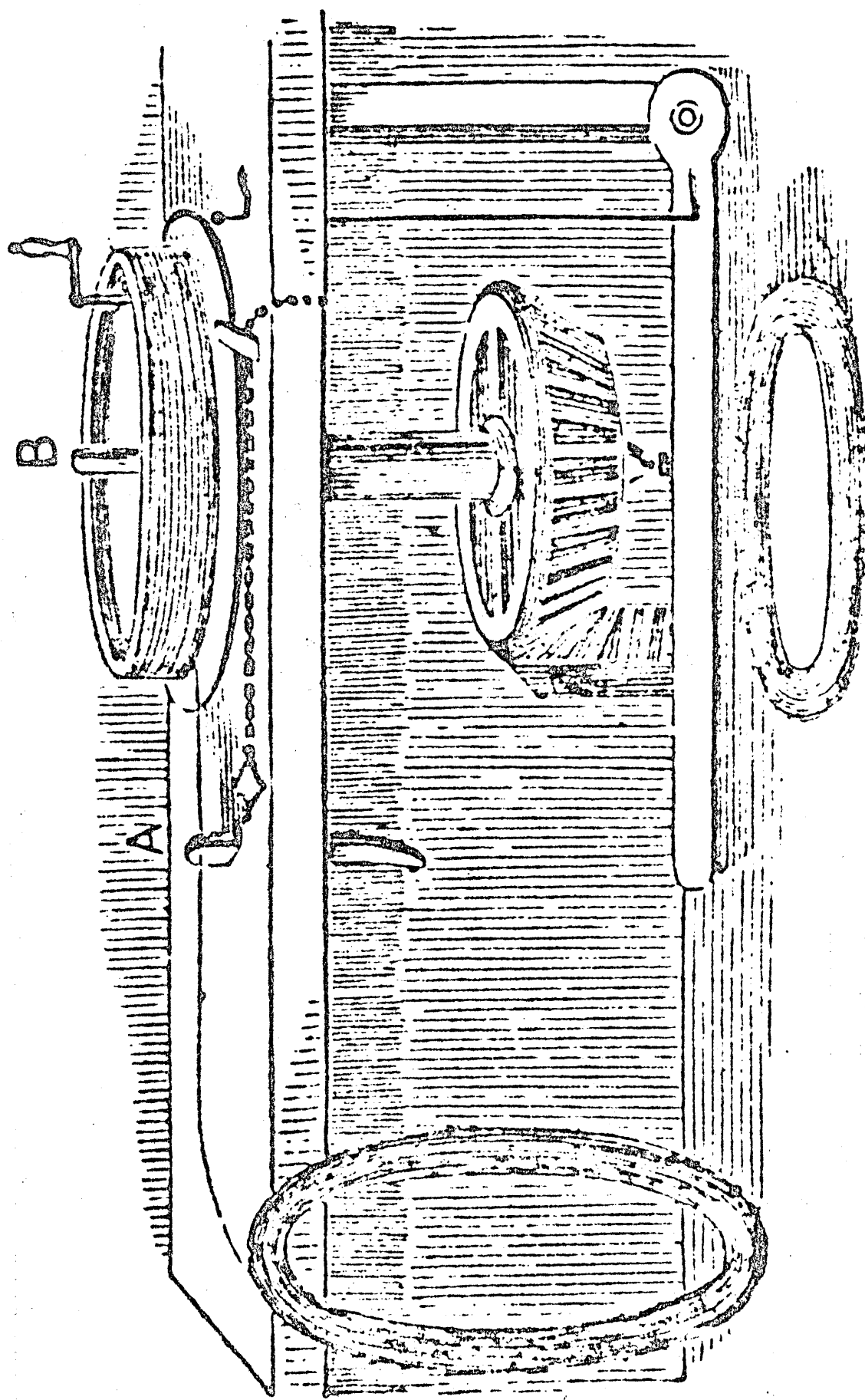
PLATE 35

Plate-makers draw-bench, circa 1790. Ibid p. 482.



SECTION OF PLATED COPPER - PRIOR
TO BEING DRAWN INTO WIRE.





Wire-drawer's Bench.

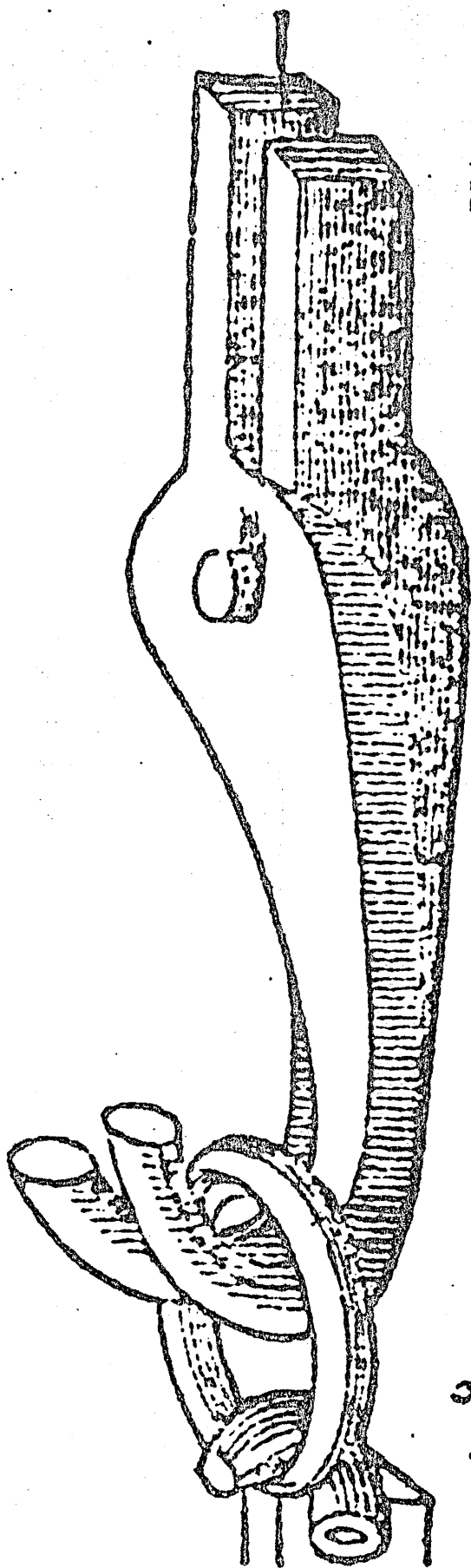


PLATE 37

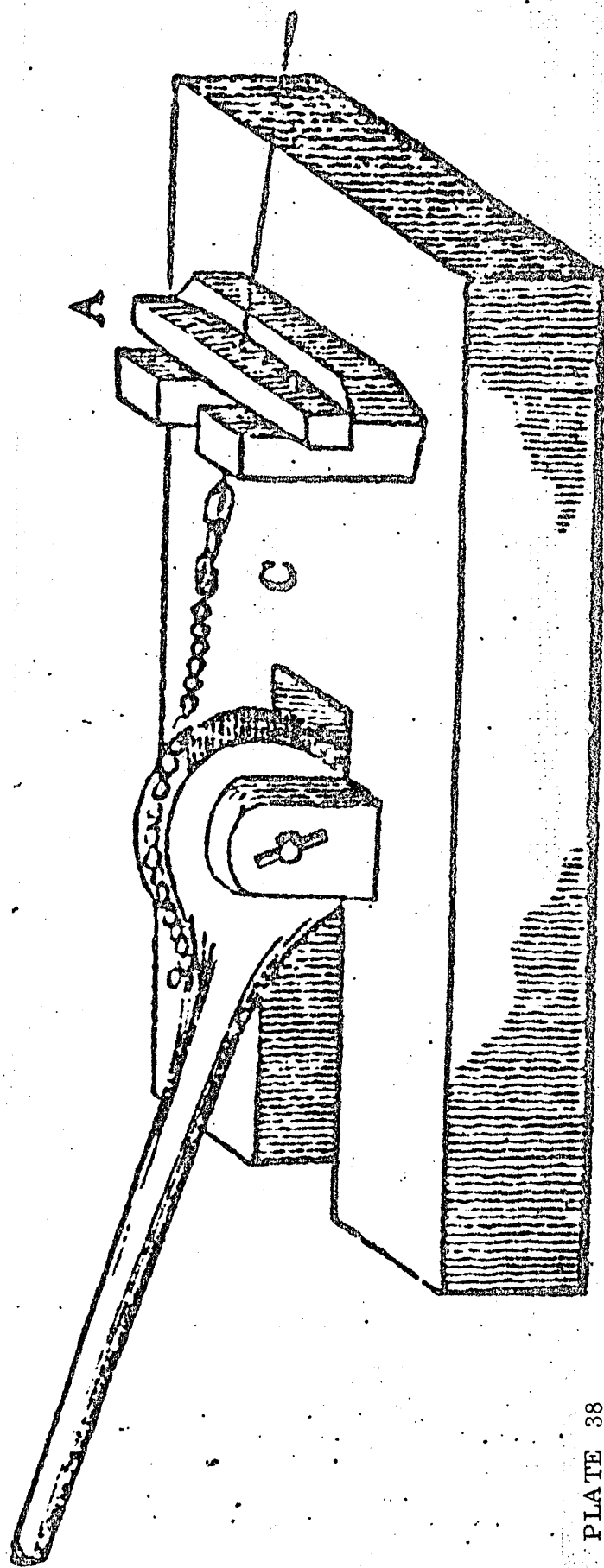
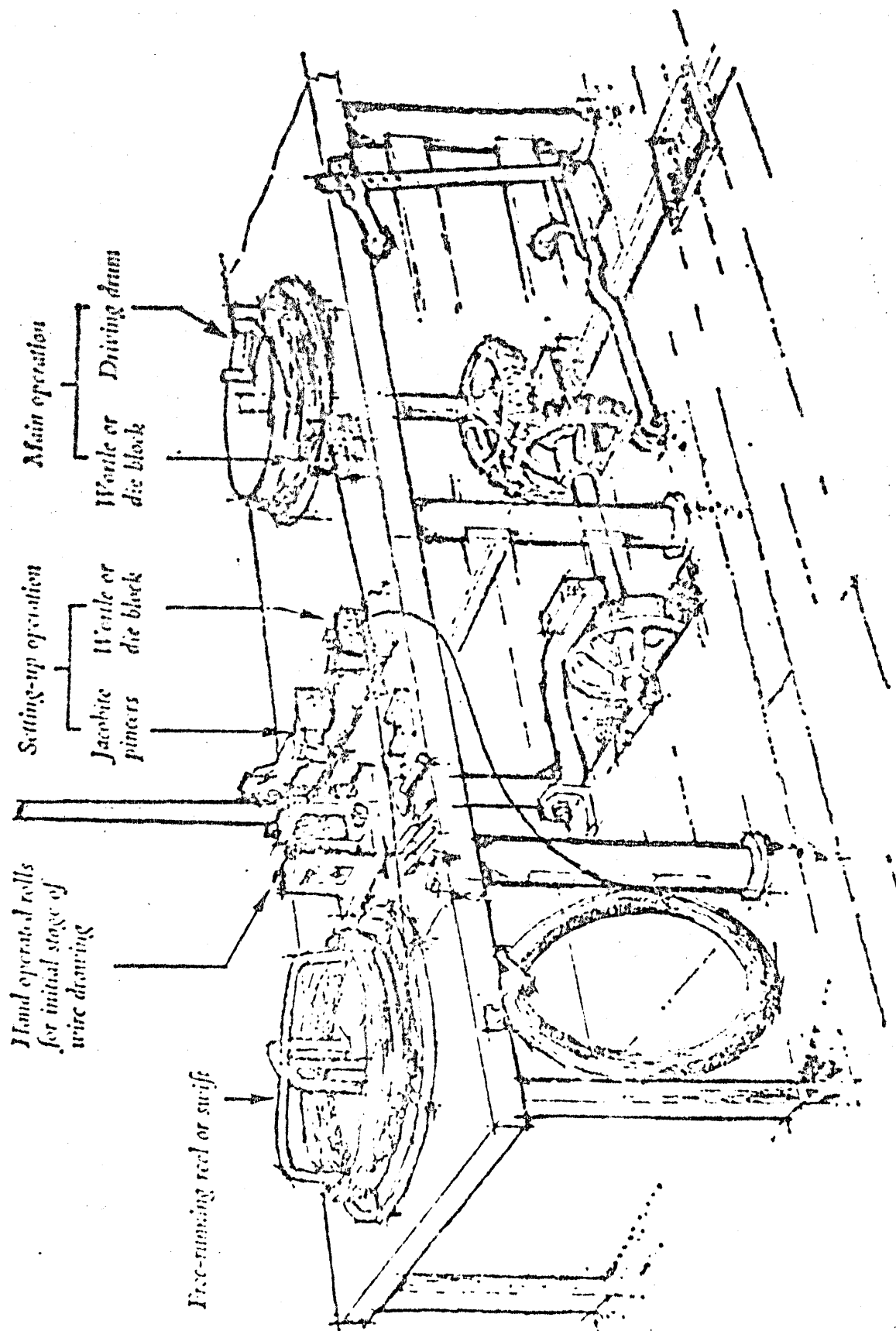
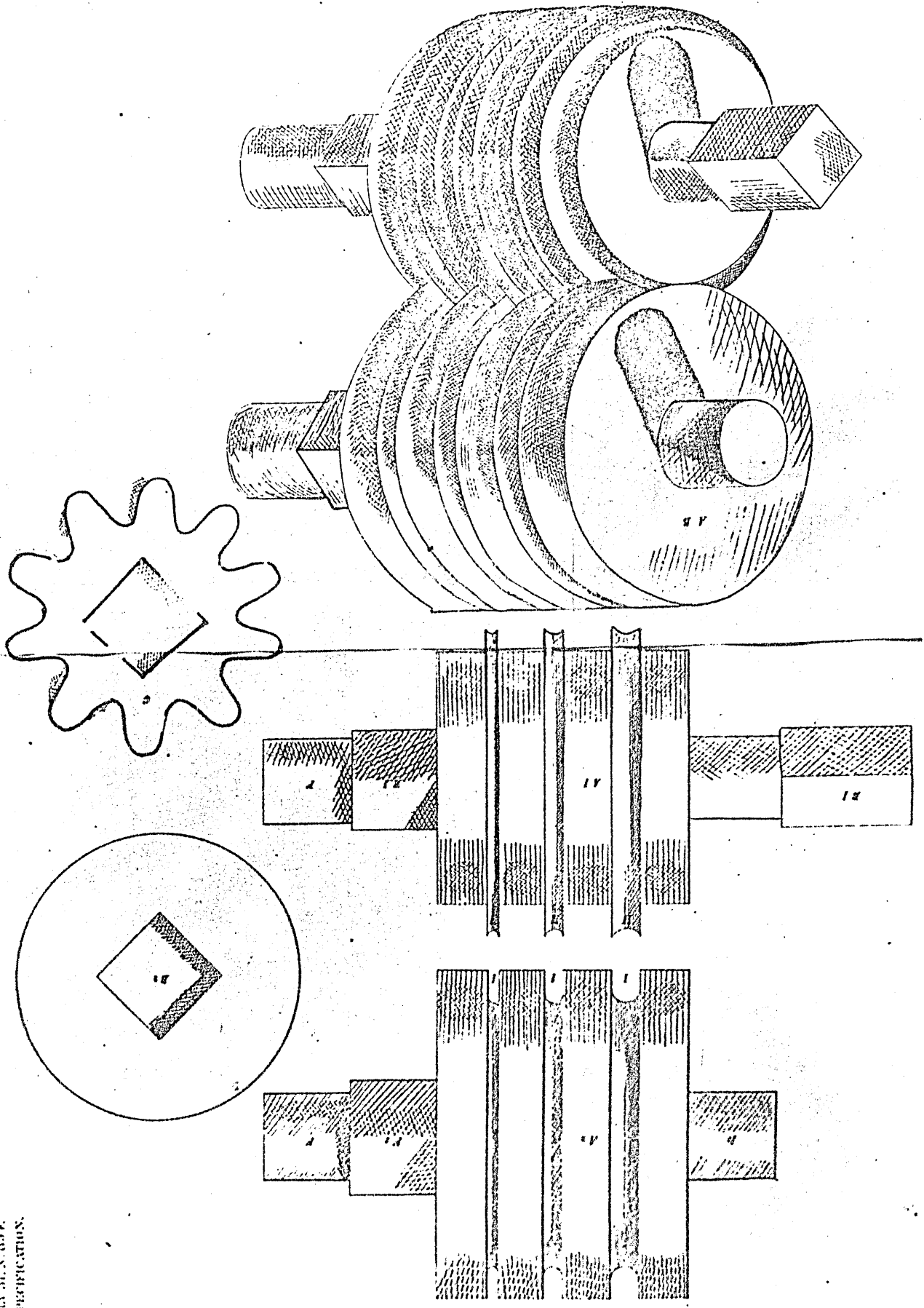
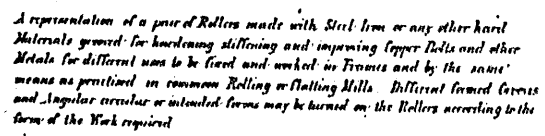


PLATE 38



REV. 31. N. 45 F.
SPECIFICATION.





LONDON. Printed by GEORGE EDWARDS LYNCH and WILLIAM SPENCER MOORE,
Printers to the Government and Excellent Majesty 1860

Дана на 5-м из М. 11.4. 1958

A.D. 1783, Oct. 2. N^o 1333.
COLLINS'S SPECIFICATION.

(1 SHEET.)

Nº 11

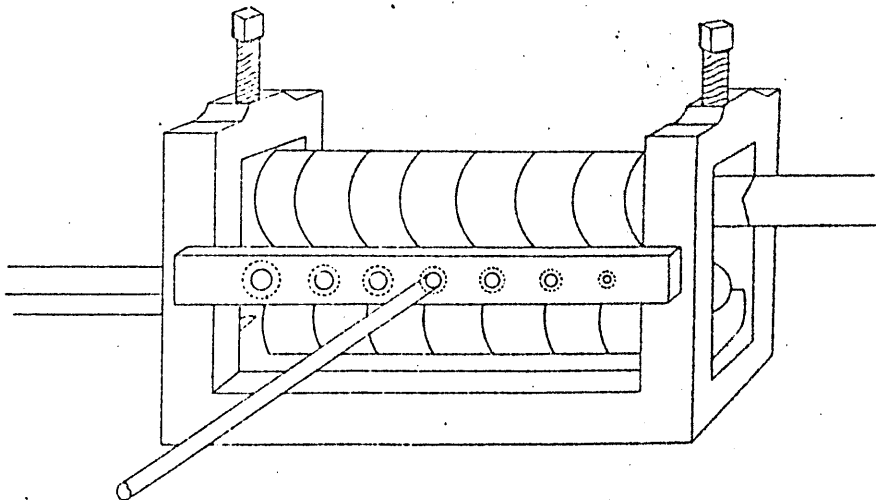
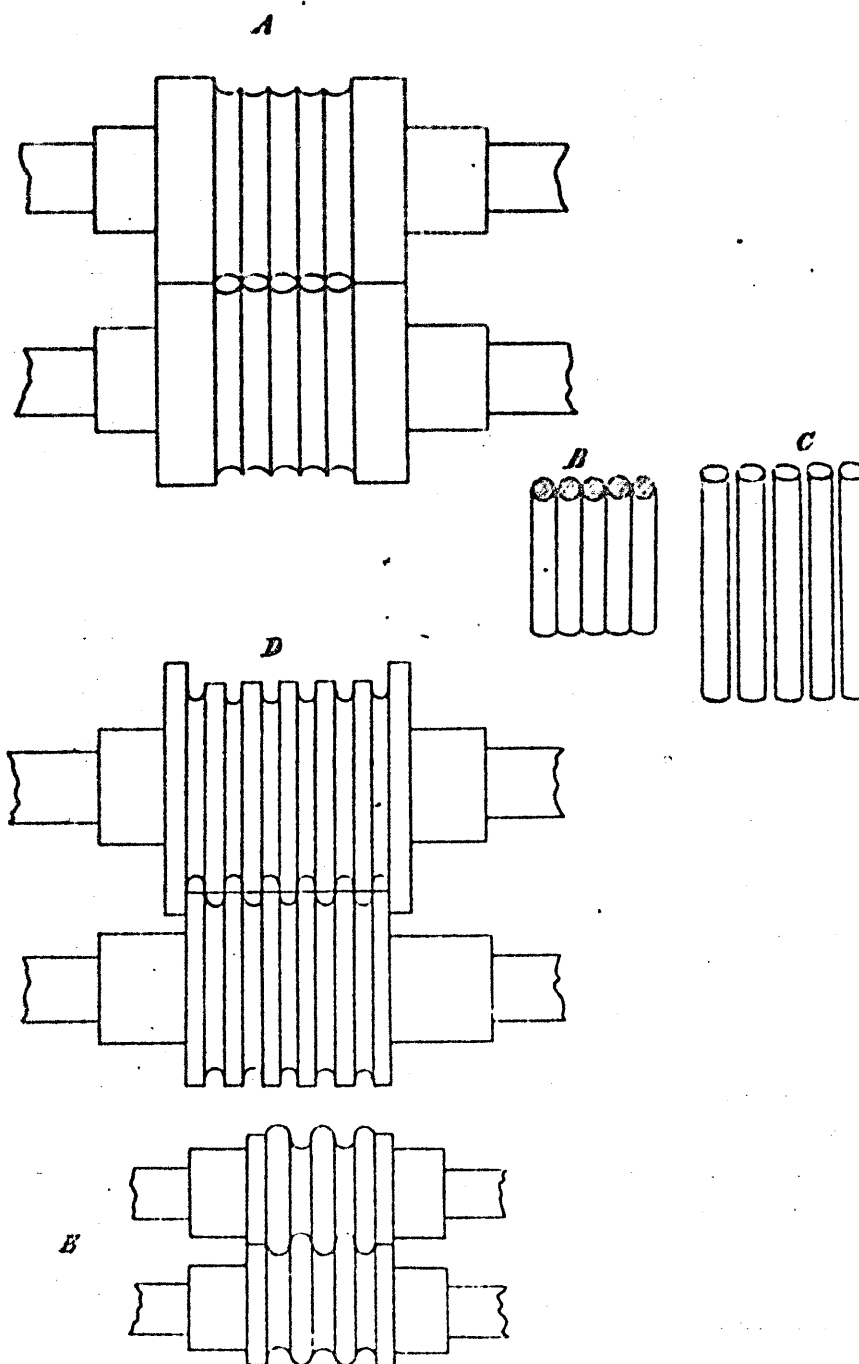


PLATE 42



The enrelled drawing is colored.

Drawn on Stone by Mally & Sons

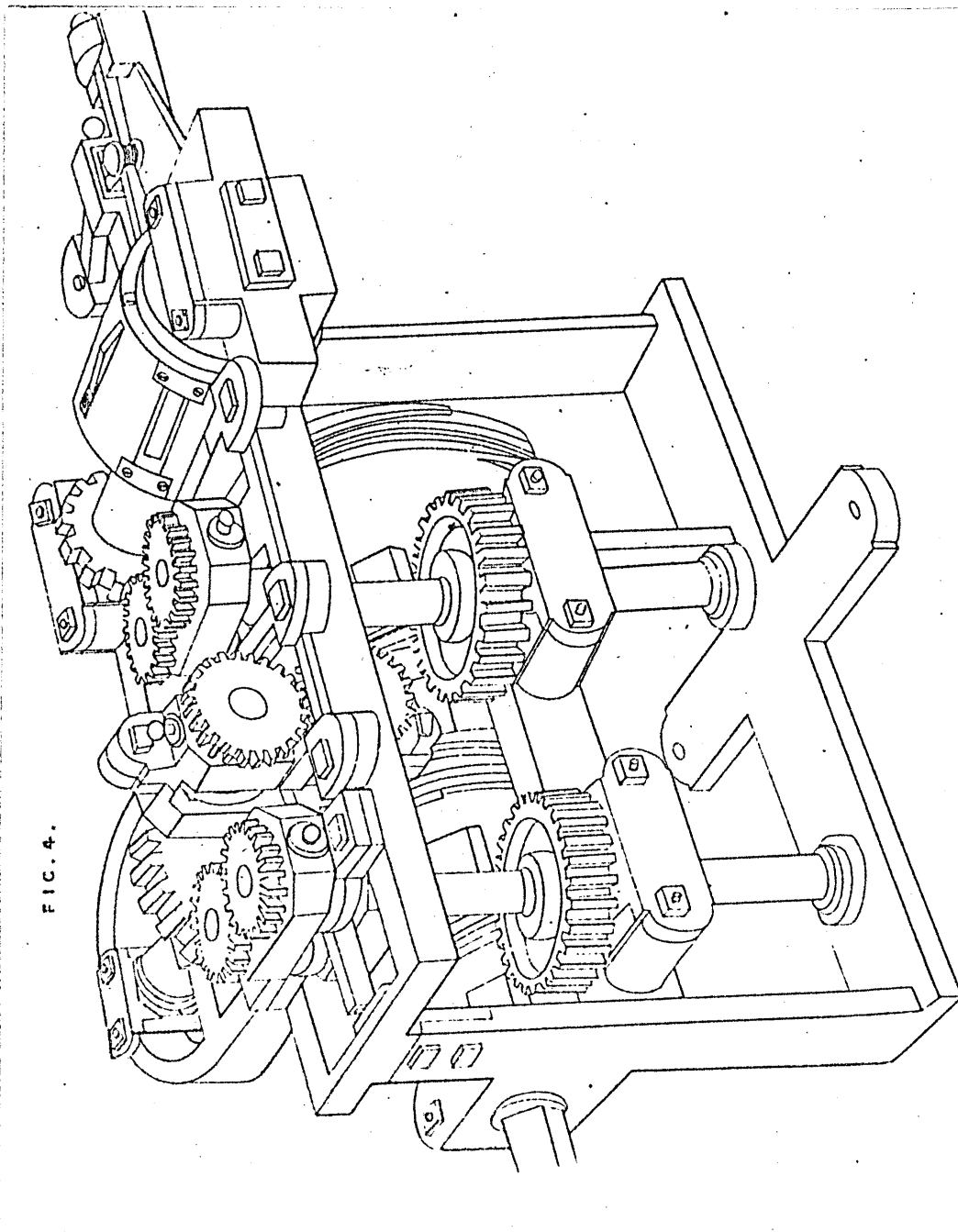
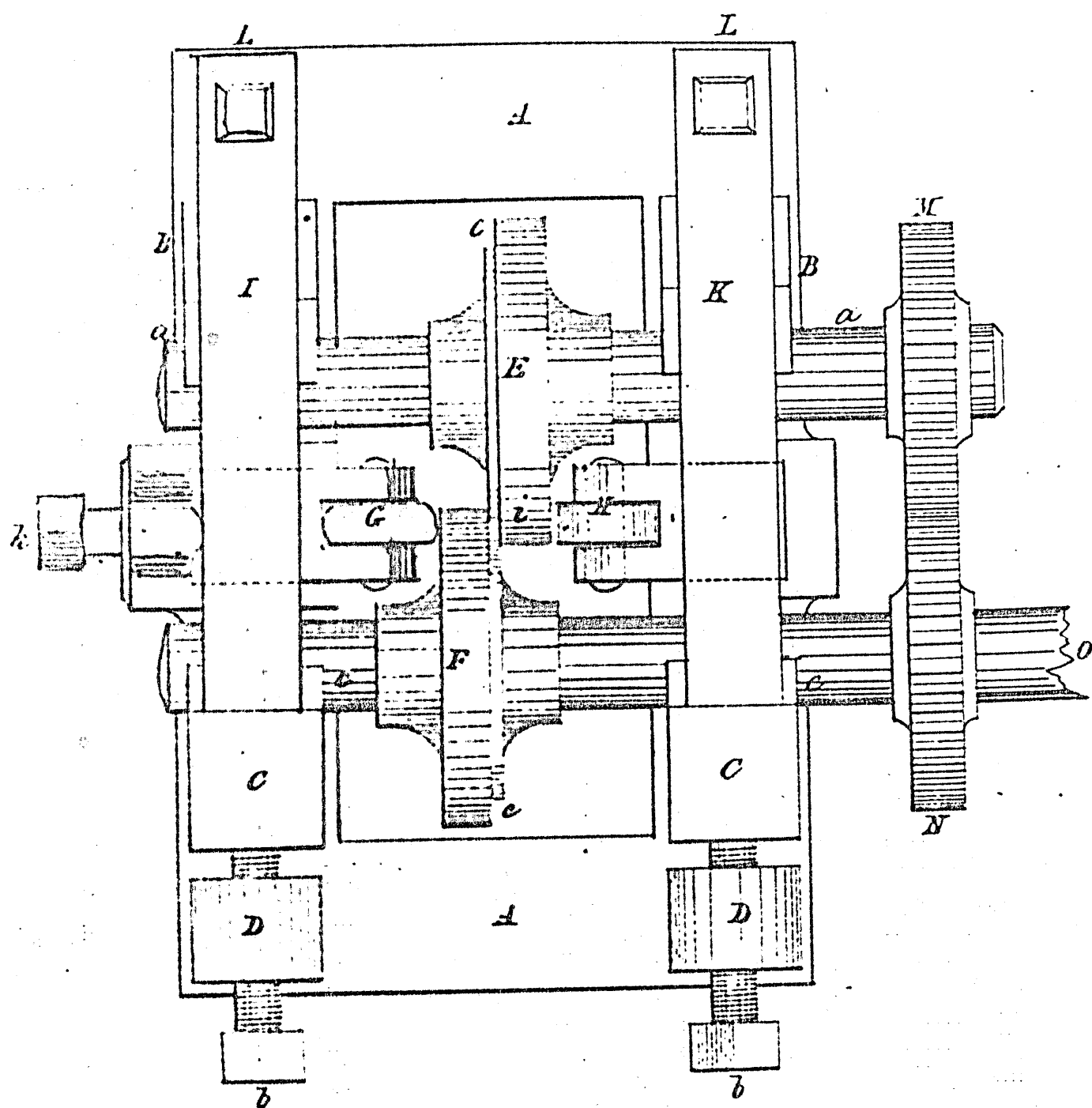


FIG. 4.

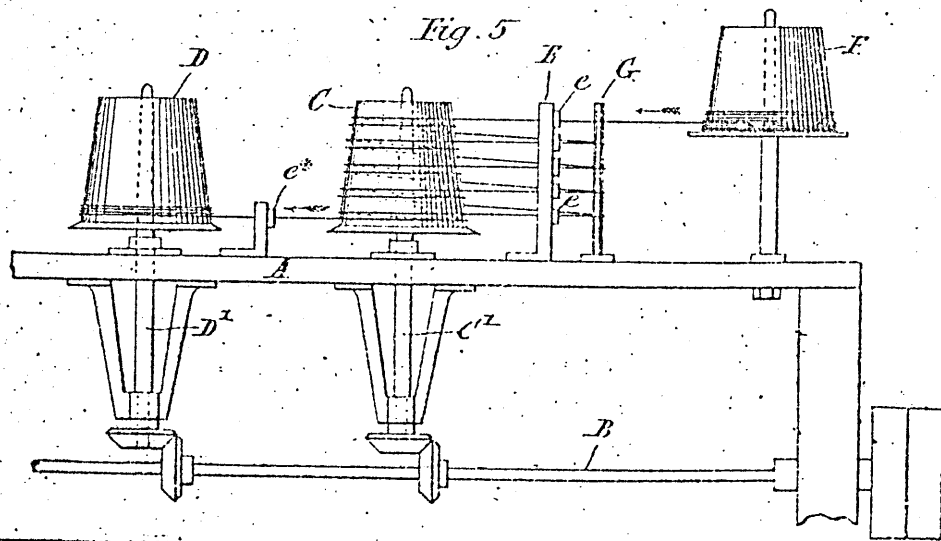
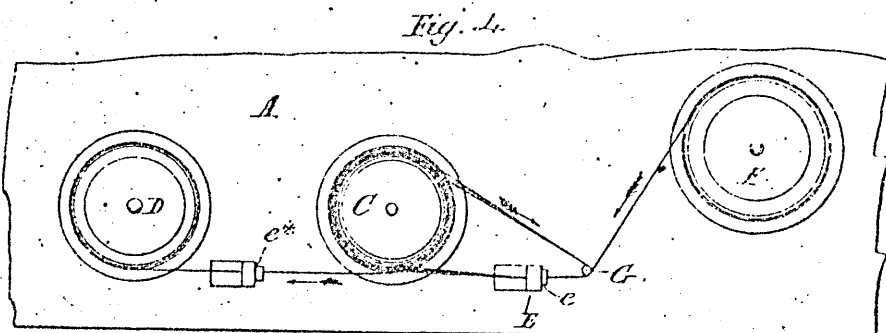
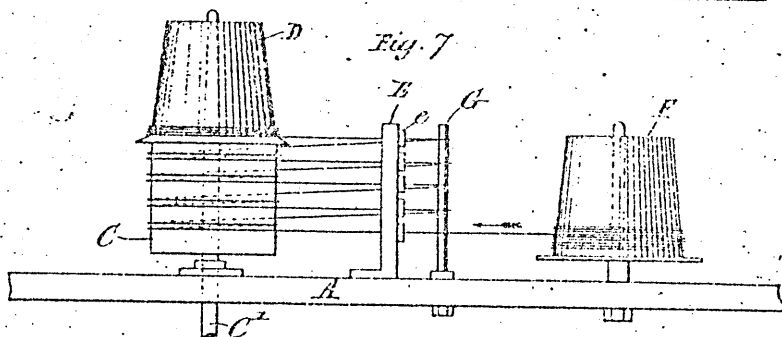
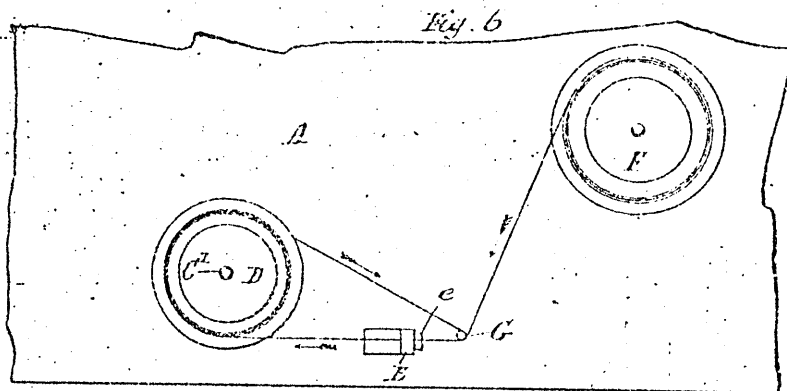
FIG. 1.



A.D. 1887. JUNE 6. N° 8133.

A. S. & T. BOLTON'S COMPLETE SPECIFICATION.

(2 SHEETS)
SHEET 2.



LONDON. Printed by DARRISS and SON
for Her Majesty's Stationery Office. 1888.

Maitly & Sons, Photo-Lithrs.

[This Drawing is a reproduction of the (original on a reduced scale)]

PLATE 36

Middle 19th century fine wire-drawing bench - from the "Cyclopaedia of Useful Arts and Manufactures" Editor - Charles Tomlinson, Virtue, London 1866 p. 911.

PLATE 37

Self-acting "grips" or tongs used on numerous wire-drawing machines up to 1927. From Holland op cit p. 336.

PLATE 38

Initial entry of wire into portable draw-plate by manual process. From Holland op cit p. 335.

PLATE 39

Wire-bench in use at the Avon Mills, Keynsham in 1927. From Day J. "Bristol Brass" David and Charles 1973 p. 161.

PLATE 40

Detail from Purnell's patent of 1766 for the rolling of rod and wire.

PLATE 41 and 42

Schematics from Westwood's and Collins's patents of 1783.

PLATE 43

Bell's specification (B.P. No. 3907) of 1815.

PLATE 44

Detail from Church's specification (B.P. No. 4258) of 1818.

PLATE 45

Detail of Todd's machine for rolling wire (B.P. No. 4257) of 1818.

PLATE 46

Schematic of Bolton's continuous wire-drawing machine of 1887. (B.P. No. 8133, June 6th 1887).

PLATE 47

Copper-wire jointed by a bell-hanger's twist - reproduced from Willoughby Smith, Jrn. Soc. Tele. Engs. Vol. 5, 1876 p. 257.

PLATE 48

Detail, Moore's draw-plate specification (B.P. No. 145) of 1860.

PLATE 49

The work floor of Walker's Wire and Rolling Mills, Birmingham circa 1851-2. From "The Visitors' Handbook Through the Manufactories of Birmingham" Cornish, Birmingham 1852.

PLATE 50

The heavy wire-drawing room at John A. Roeblings & Sons Company. Approximately 1900. From Perrin F. C. "Conductors For Electrical Distribution" Von Nostrand 1903.

PLATE 51

Drawing telegraph wire at Roeblings. Ibid.

PLATE 52

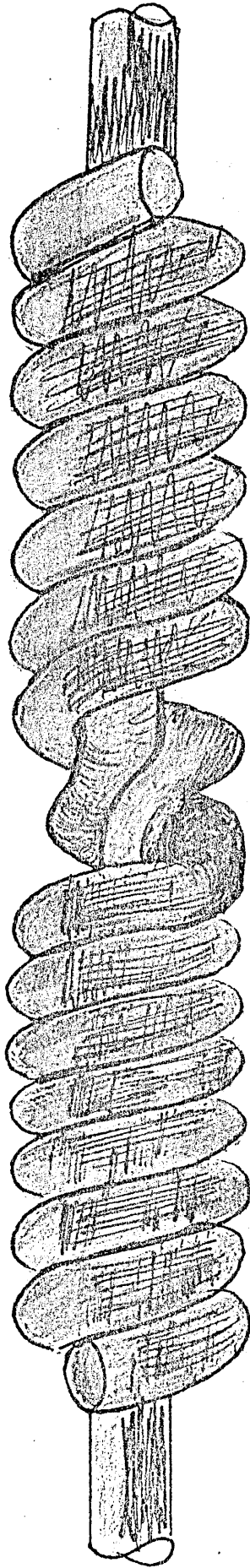
Draw-plate, circa 1900. Ibid.

PLATE 53

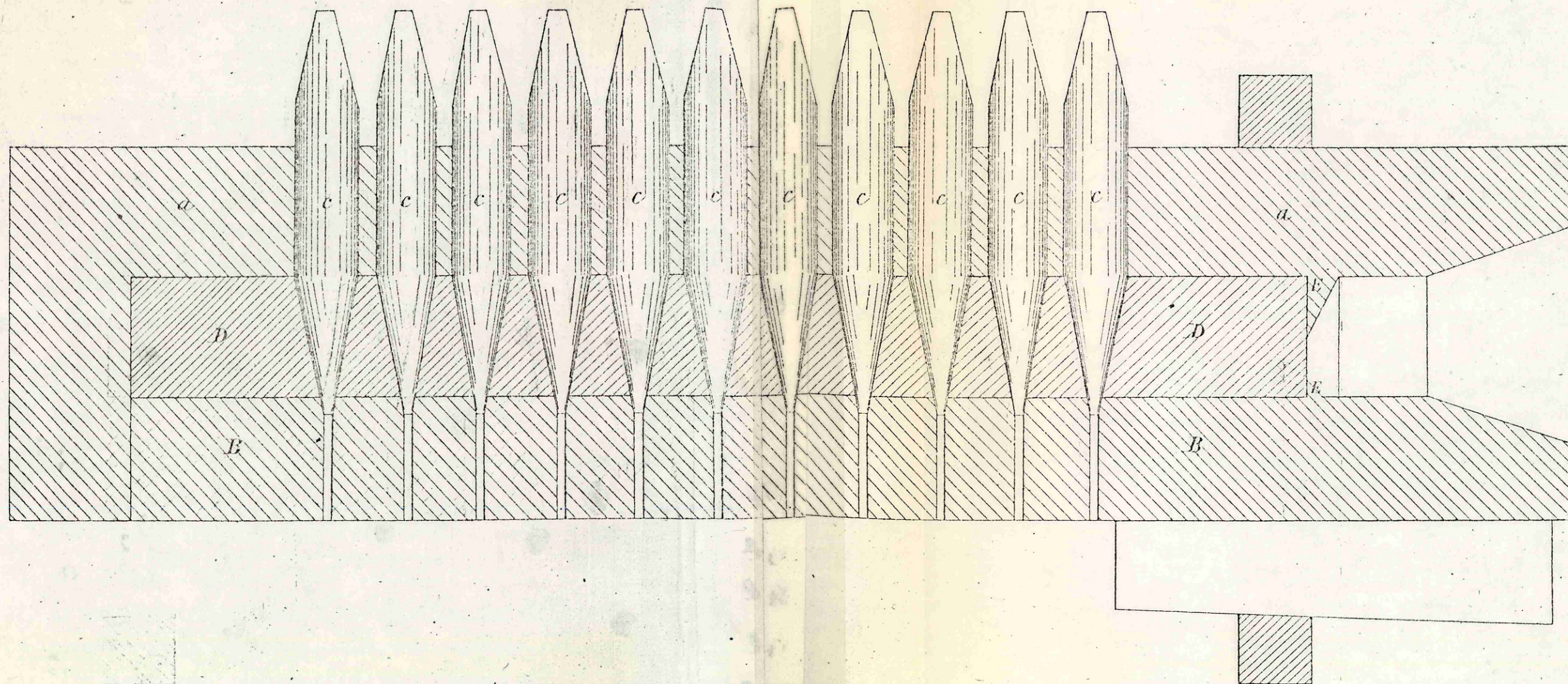
Steel and cast iron dies and draw-plates. Ibid.

PLATE 54

Detail - self-acting grips . From the machine by Daner, see Plate 18.

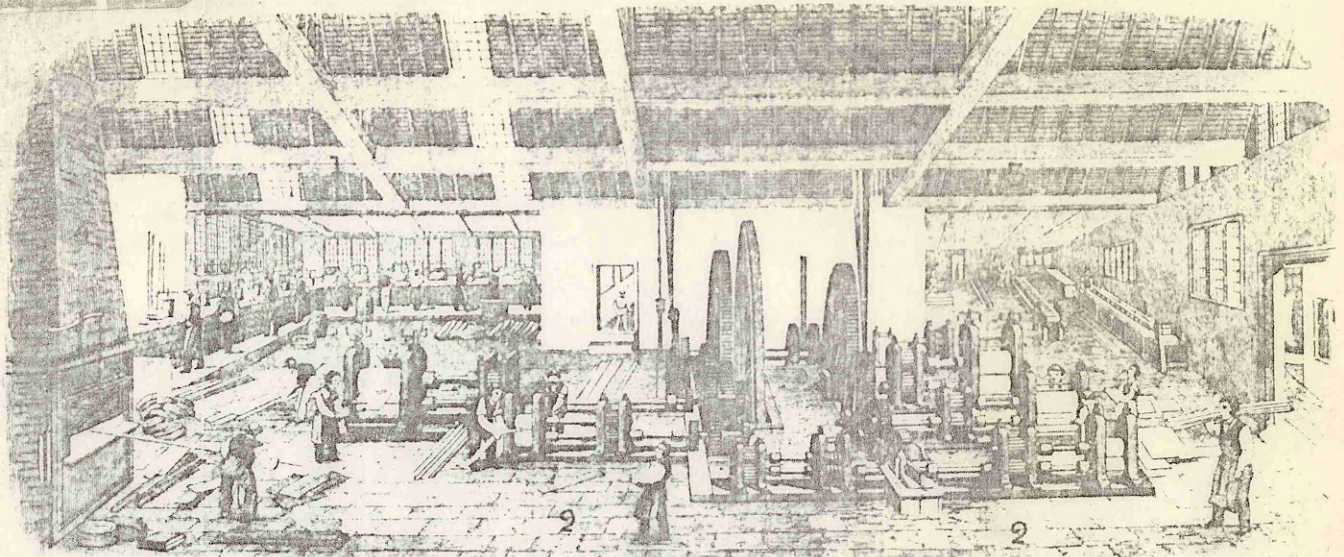


BELL-HANGER'S TWIST

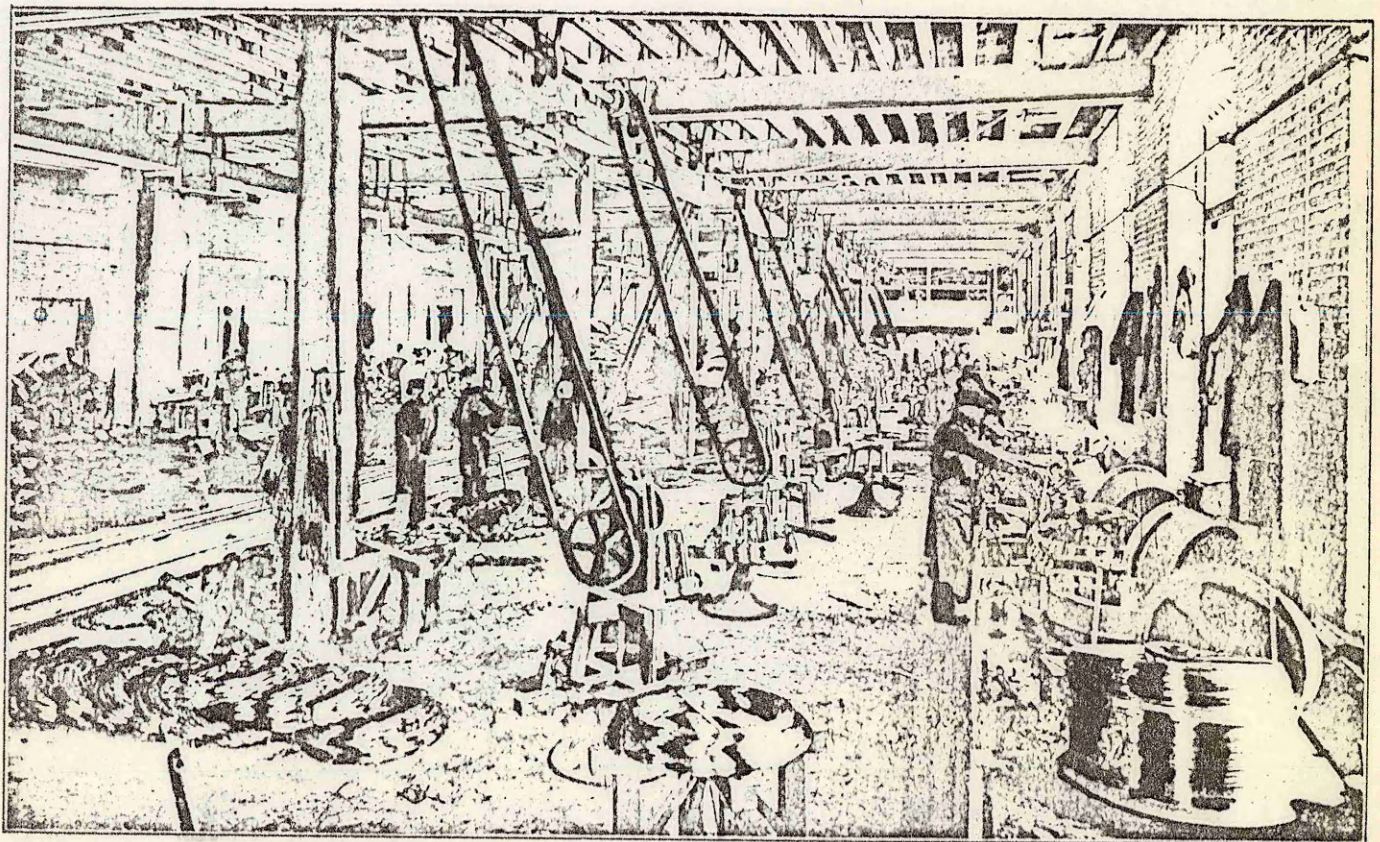


The filed drawing is not colored.

Drawn on Stone by Malby & Sons.



1. WIRE MILL. 2. ROLLING MILL. 3. TUBE MILL. 4. ANNEALING MUFFLE



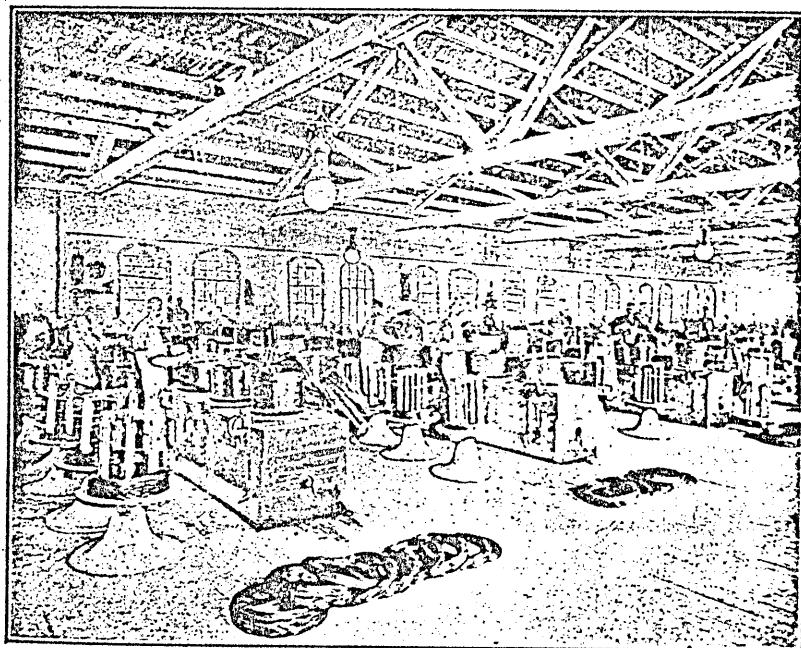


PLATE 51

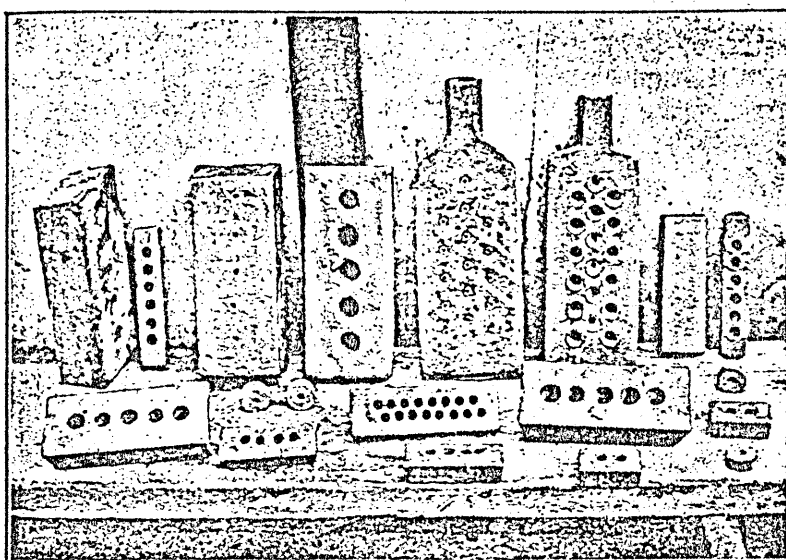


PLATE 52

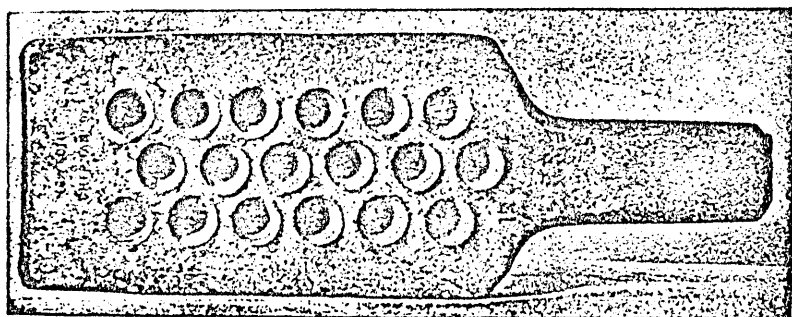


PLATE 53

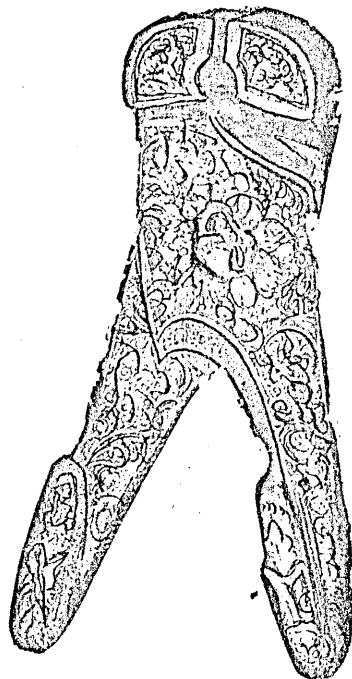
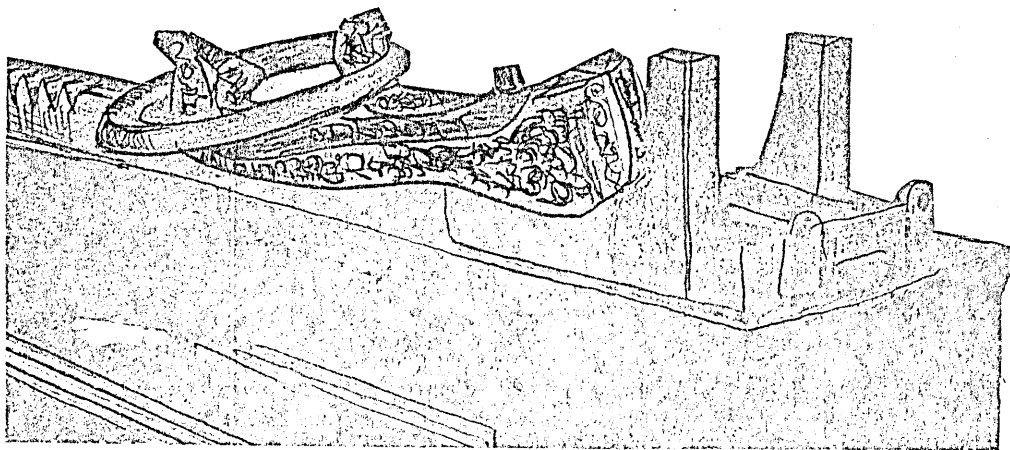


PLATE 54



The Rise of Copper Wire , Its
Manufacture and Use to 1900 - A
Case of Industrial Circumspection.

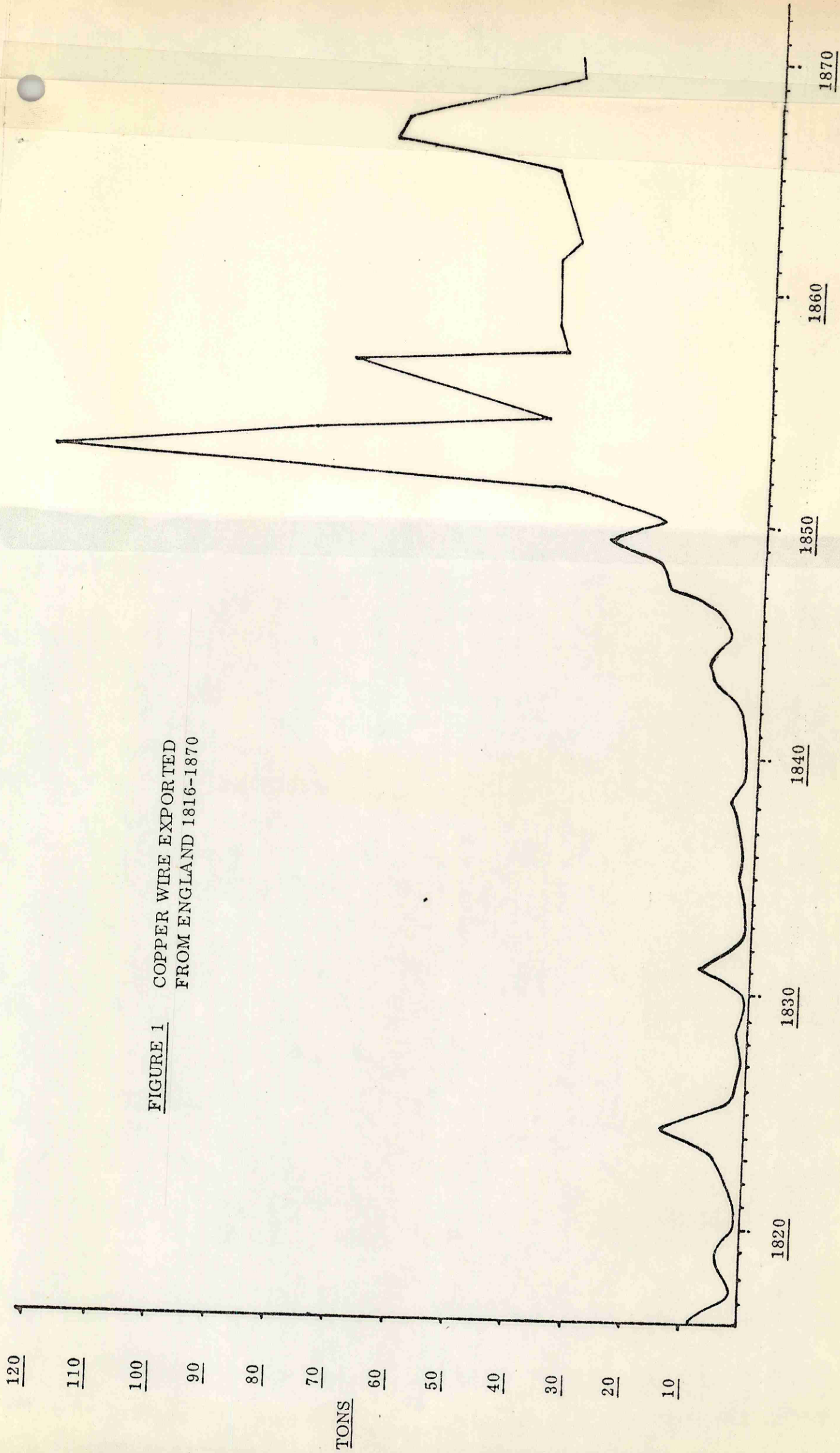
=====
TABLES AND GRAPHS.

Barrie C. Blake-Coleman.

1980

APPENDIX 1- GRAPHS AND HISTOGRAMS.

FIGURE 1
COPPER WIRE EXPORTED
FROM ENGLAND 1816-1870



50

40

30

20

10

FIGURE 2 THE MEAN ANNUAL EXPORT OF
COPPER WIRE TAKEN OVER
DECENNIAL PERIODS:- 1810-1870

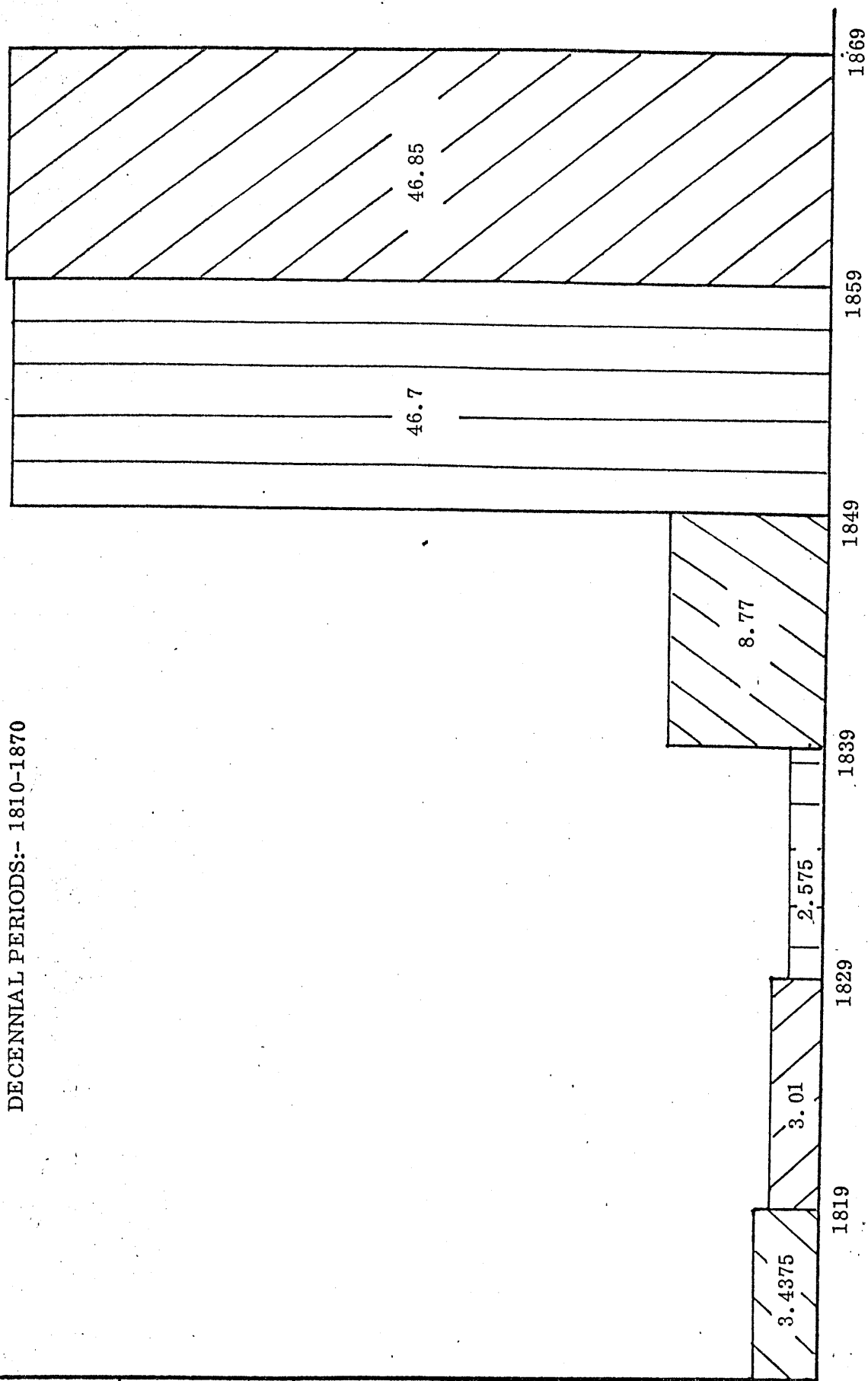


FIGURE 3 THE PRICE OF 'TOUGH' ENGLISH COPPER (PER TON)
AS COMPARED TO ENGLISH COPPER WIRE (PER POUND)
1810-1900

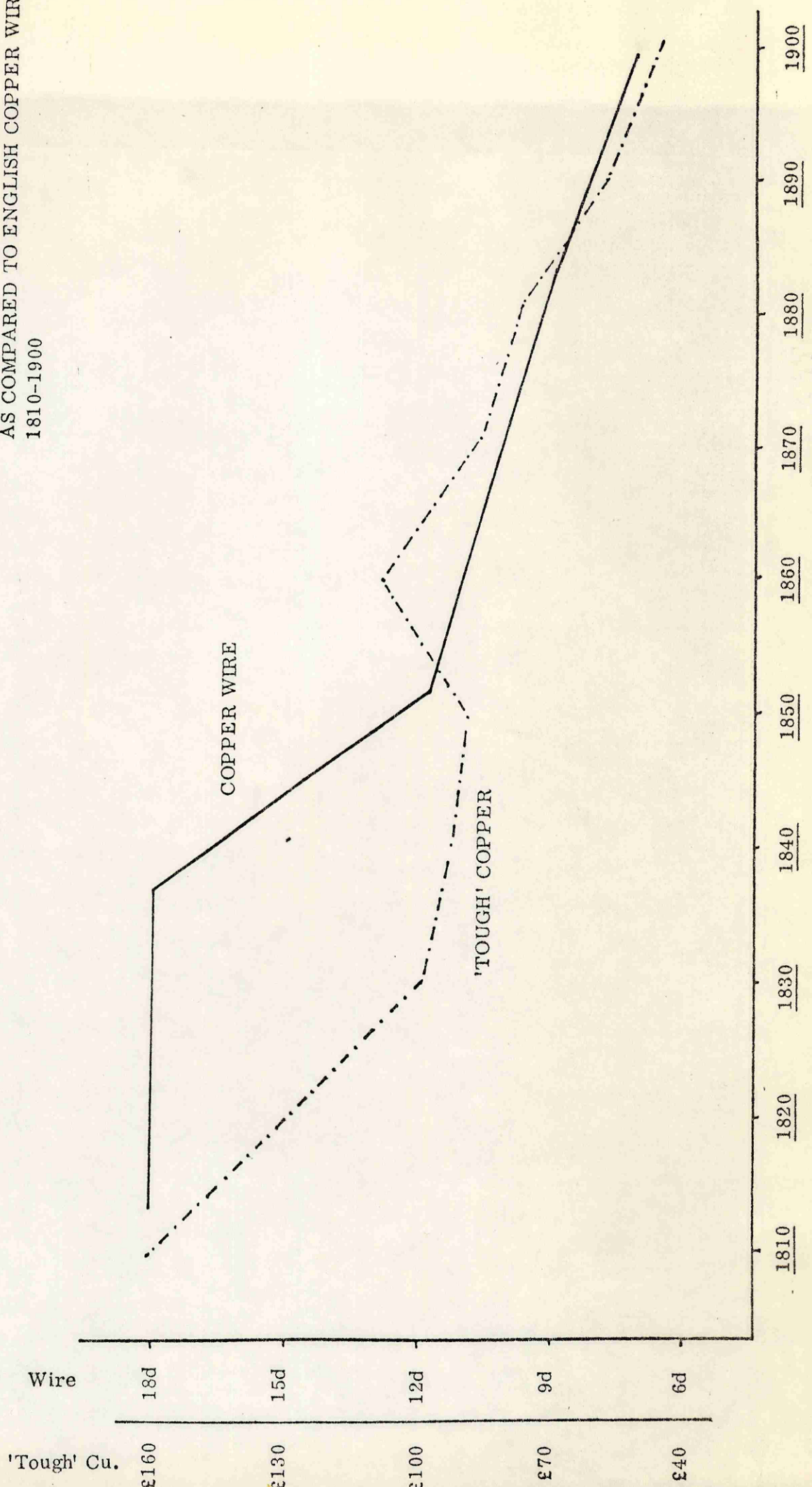


FIGURE 4

THE PRICE OF ENGLISH COPPER AS
COMPARED TO EXPORTS OF COPPER
WIRE FROM ENGLAND - TAKEN AS
THE MEAN OF DECENNIAL PERIODS:-
1816-1880

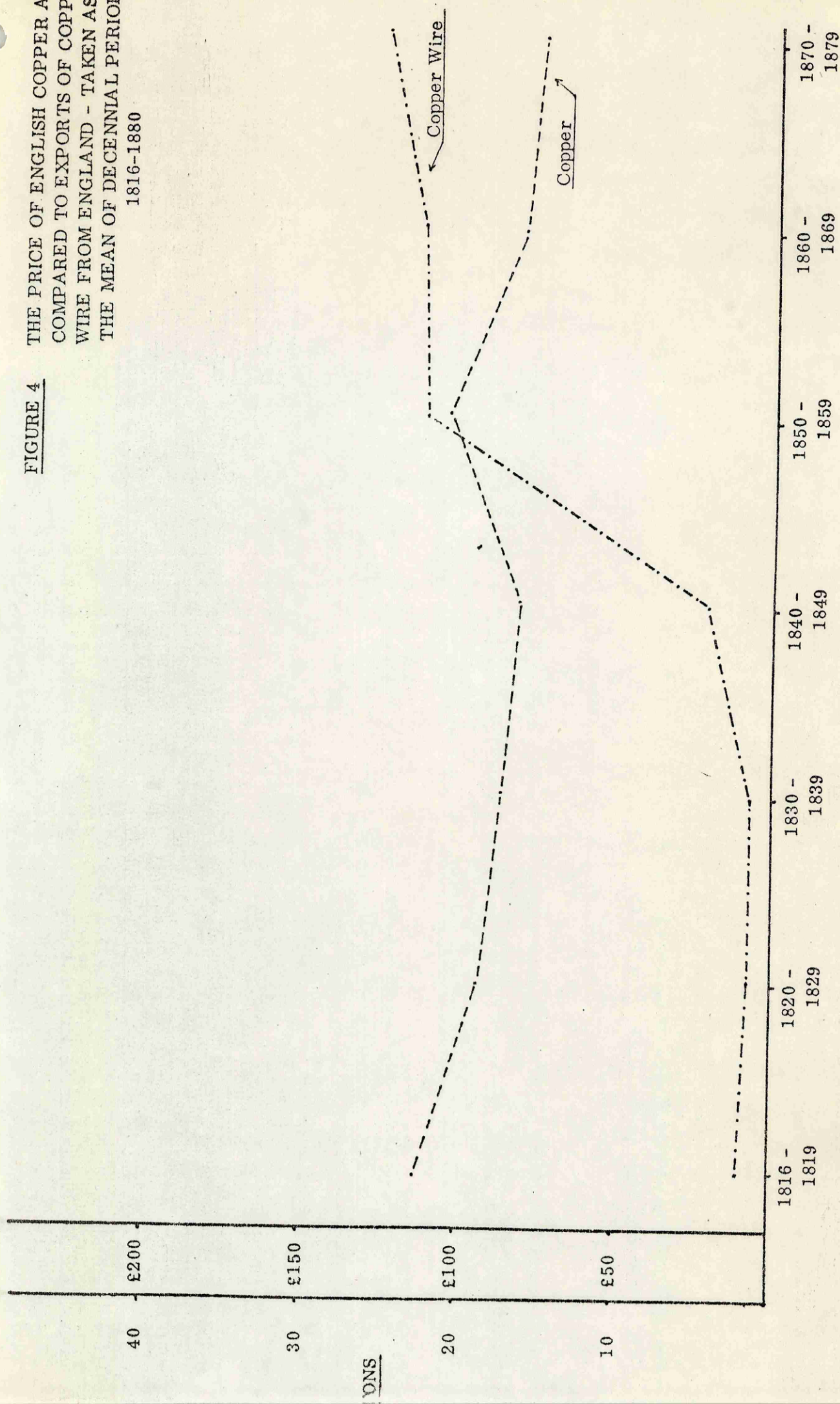
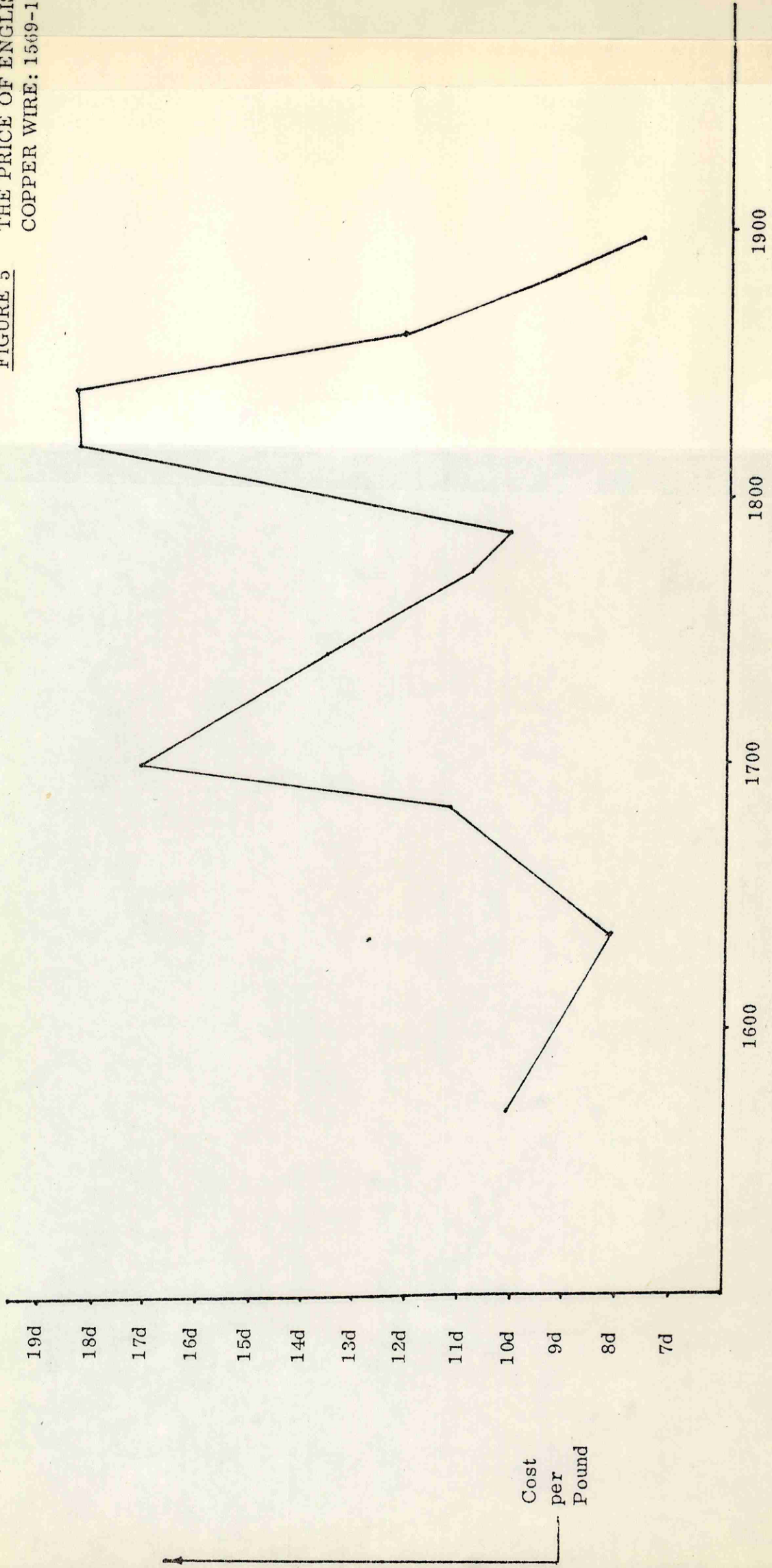


FIGURE 5 THE PRICE OF ENGLISH
COPPER WIRE: 1569-1900



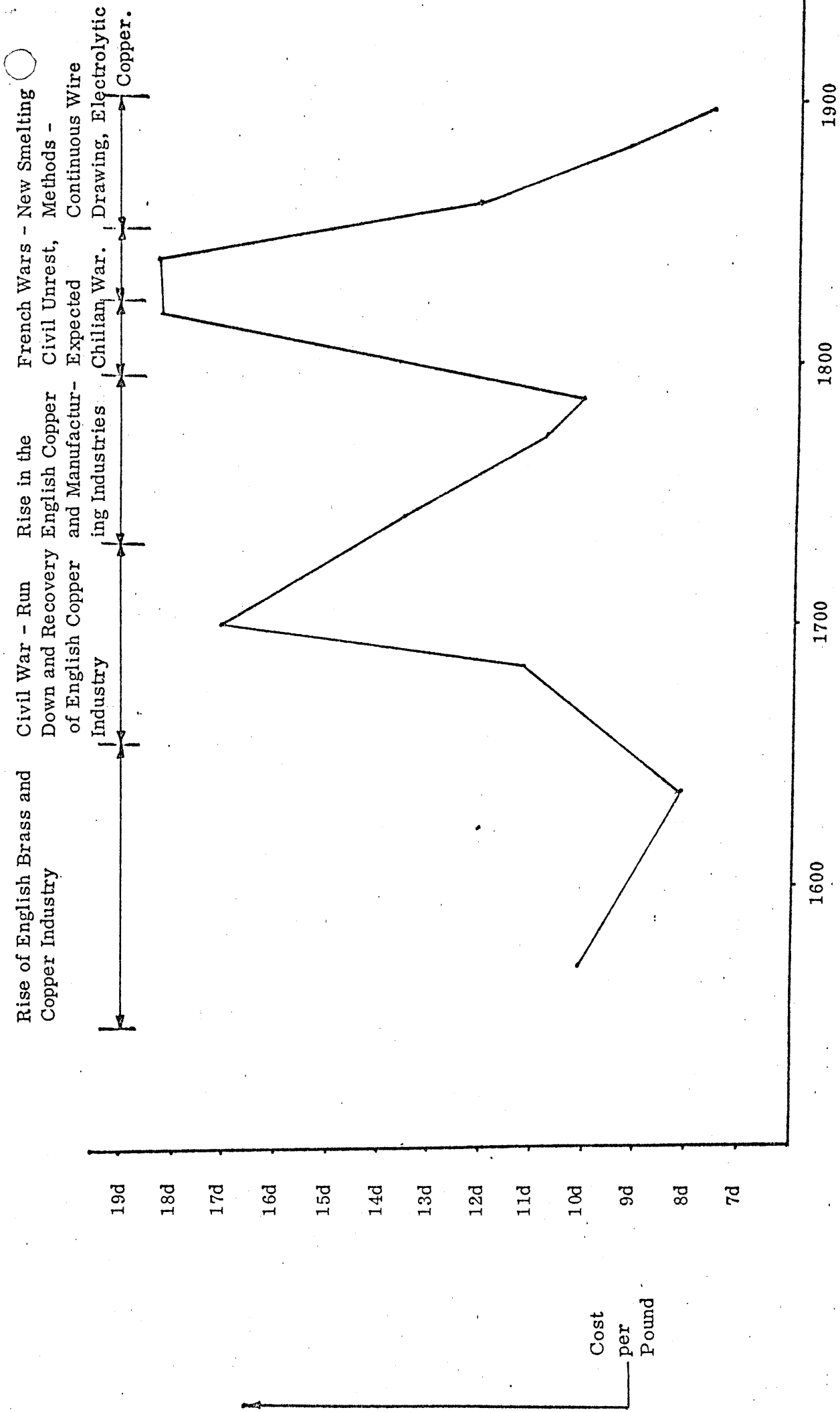
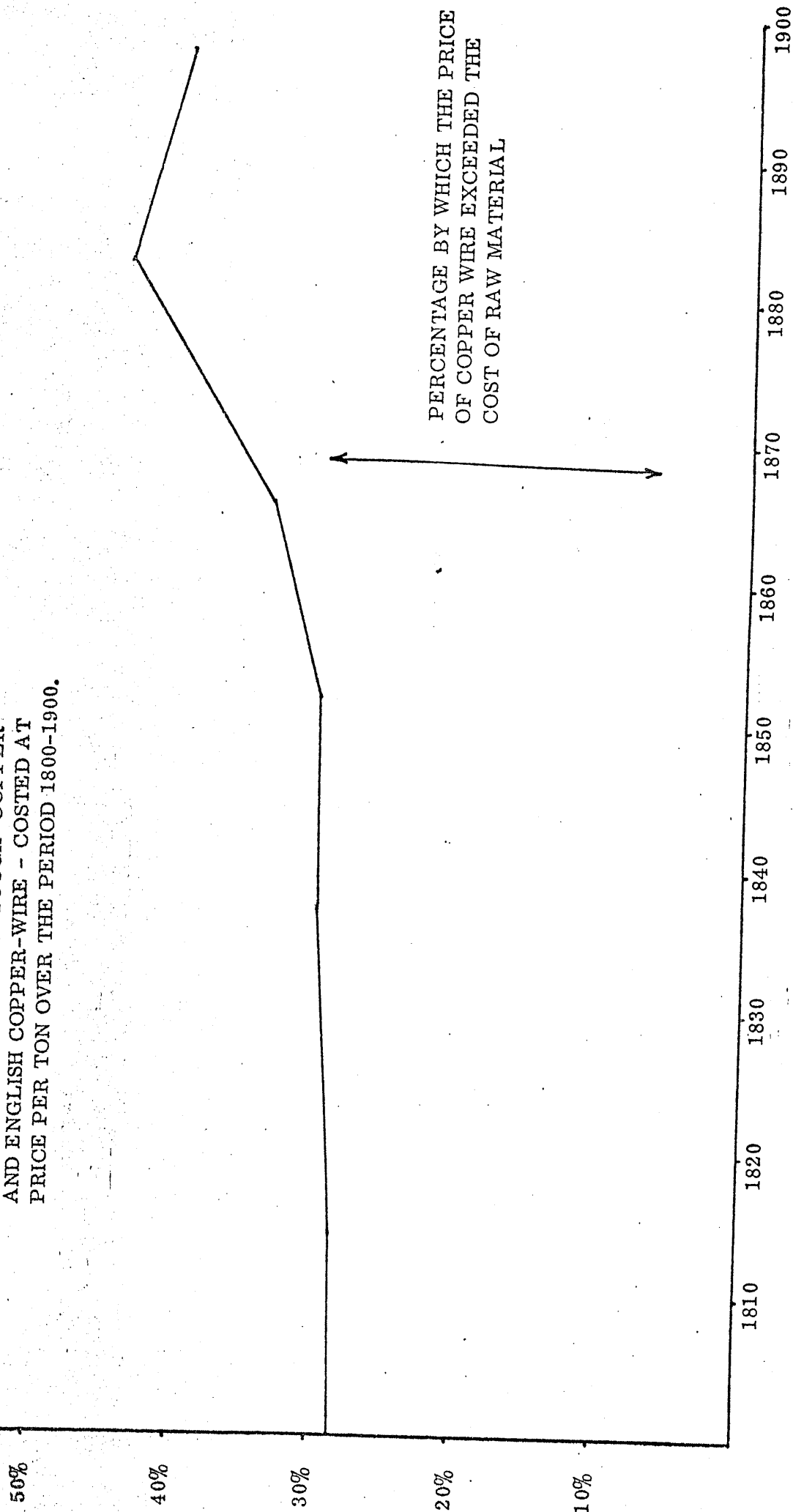


FIGURE 6 PRINCIPAL SOCIO-ECONOMIC FACTORS INFLUENCING THE COST OF COPPER WIRE - 1569-1900.

FIGURE 7

THE PERCENTAGE MARGIN BETWEEN
THE PRICE OF ENGLISH 'TOUGH' COPPER
AND ENGLISH COPPER-WIRE - COSTED AT
PRICE PER TON OVER THE PERIOD 1800-1900.



APPENDIX 2 - GRAPHS AND TABLES.

TABLE 1

	Fe ^{A1}	Cu ^{A1}	A2	A3	A4	A5	A6	A7	A8	A9	A10
Cu	-	99.0	99.3	99.4	99.6	98.6	99.4	99.8	99.7	99.6	99.9
Fe	99.9	-	-	0.001	0.001	-	0.0012	-	-	-	0.021
Ag	-	0.0928	0.111	0.115	0.0511	0.123	0.082	0.0195	0.0913	0.0976	0.0011
Ni	-	0.0545	0.0519	0.0309	0.0460	0.0411	0.0426	0.0019	0.0352	0.0449	0.0019
Co	0.0022	-	-	-	-	-	-	-	-	-	-
Zn	-	0.0031	0.0021	0.0051	0.0069	0.0026	0.0014	0.0136	0.0023	0.0016	0.0024
Pb	-	0.147	0.431	0.35	0.232	0.817	0.355	0.0046	0.234	0.21	0.007
Sn	-	0.0324	0.0381	0.0225	0.0324	0.388	0.0288	0.0479	0.0296	0.0296	0.0073
As	-	0.395	nd	nd	nd	nd	nd	nd	nd	nd	nd
Mag'	35	33	5	8	11	14	1	17	21	25/26	30
and	36/37	-	-	9	12	15	2	18	22	28	31
Frame No.		34	6/7	10	13	16	3	19	23	29	32

nd:- Not determined.

Table 1 - A1 to A10 refers to the sample labelling; for the nine Faraday samples (A1 to A9) sample A1 includes the assay for an iron wire winding found in the same coil. Sample A10 refers to the Cavendish sample, while the lower section of the Table indicates the number and magnification of electron-micrographs.

TABLE 3

COMPARISON BETWEEN PREDICTED AND MEASURED RESISTIVITIES

SAMPLE	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
ρ (predicted) ($\Omega/\text{gm-m}$)	0.3734	0.2395	0.2512	0.2238	1.4*	0.2513	0.1605	0.1916	0.1960	0.5435
ρ (measured) ($\Omega/\text{gm-m}$)	0.4033	0.2550	0.2362	0.2270	0.2834	0.2484	0.1518	0.2211	0.2246	0.4119*
% I.A.C.S.	37.4	59.1	63.9	66.4	53.2	60.7	99.4	68.2	67.2	36.6

* A5 and A10 : not well established

I.A.C.S. Conductivity as a percentage of the International Annealed Copper Standard
(for which $\rho = 0.15083 \Omega/\text{gm-m}$ at 20°C).

FIG 1 PREDICTED VERSUS MEASURED RESISTIVITY VALUES
 FOR WIRE SAMPLES 1 - 4 AND 6 - 10.
 SAMPLE A5 NOT INCLUDED DUE TO CONTAMINATION
 DURING ASSAY. *THIS VALUE NOT WELL ESTABLISHED.

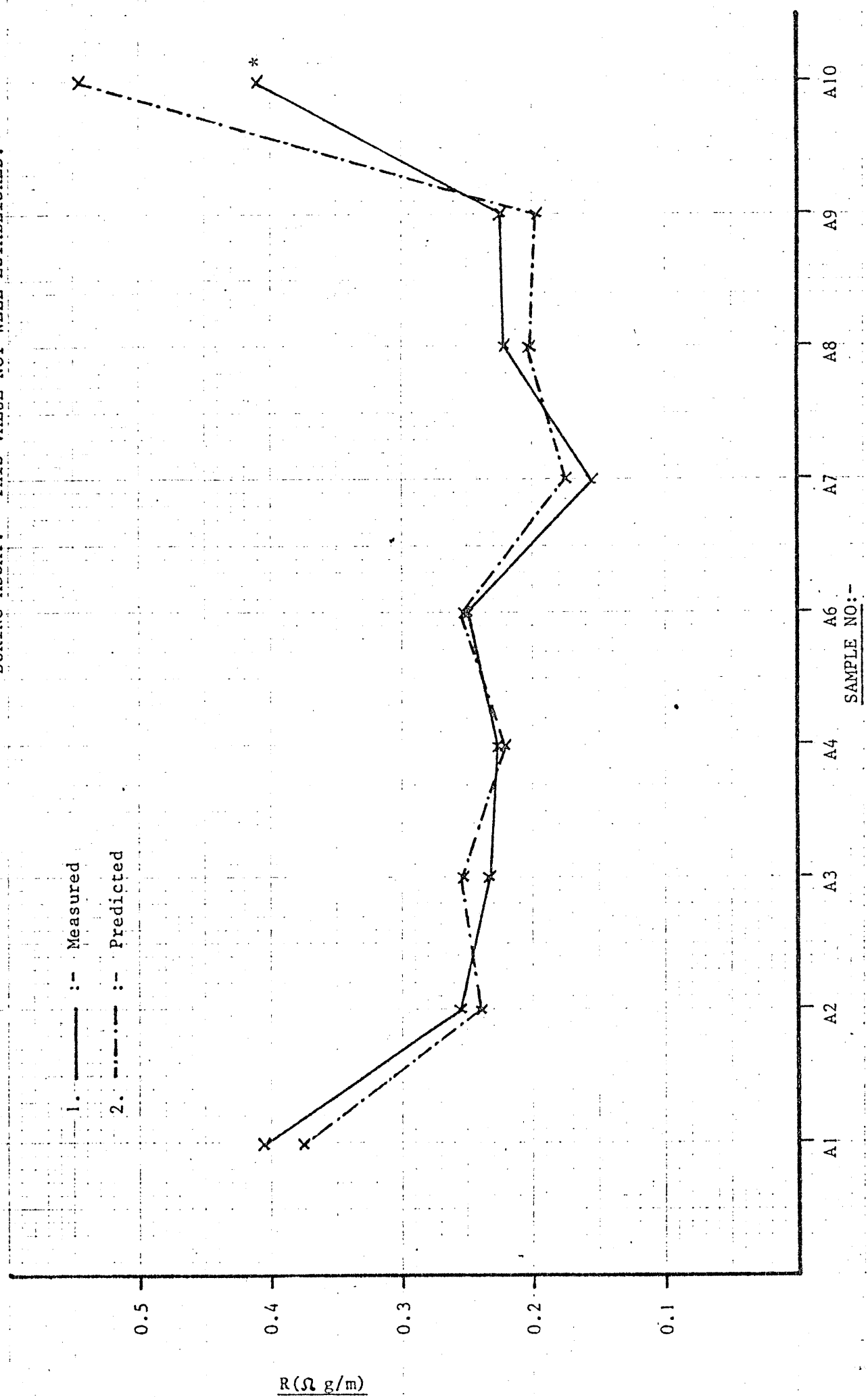


TABLE 2

1	2	3	4	5	6	7	8	9
SAMPLE	Resistance R ($\mu\Omega$) corrected to 20°C	Overall Length λ (mm)	Resistance Length λ_R (mm)	Mean Diameter (Measured) (mm)	Mass M (gm)	Apparent Specific Gravity	Volume Resistivity $\rho_v(\Omega\text{-m})$ $\times 10^{-8}$	Mass Resistivity $\rho(\Omega\text{-gm m}^{-2})$
A1(i)	153.6	29.68	23.795	2.95	1.8401	9.07	4.467	0.4002
A1(ii)	112.9	29.595	17.35	2.95	1.8344	9.07	4.501	0.4033
A2	233.4	17.21	10.85	1.28	0.2040	9.21	2.846	0.2550
A3	907.9	19.74	14.72	0.75	0.0756	8.66	2.636	0.2362
A4	265.8	29.40	14.03	1.27	0.3523	9.46	2.534	0.2270
A5	501.2	23.47	17.55	1.16	0.2329	9.39	3.163	0.2834
A6(i)	304.0	74.77	63.33	2.72	3.8771	8.92	2.778	0.2489
A6(ii)	261.9	64.895	54.60	2.715	3.3603	8.94	2.772	0.2484
A7	774.4	10.43	6.36	0.43	0.0130	8.58	1.694	0.1518
A8(i)	89.8	30.10	19.20	2.60	1.4258	8.92	2.472	0.2215
A8(ii)	135.8	25.76	18.17	2.075	0.7619	8.75	2.468	0.2211
A9	88.05	7.79	4.63	1.30	0.0920	8.90	2.507	0.2246

Mean = 8.98